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STREAM CHANNEL STABILITY. APPENDIX E. GEOMORPHIC CONTROLS OF CH--ETC(U)
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STREAM CHANNEL STABILITY

APPENDIX E

GEOMORPHIC CONTROLS OF CHANNEL STABILITY

Project Objective 5

by

E. H. Grissinger and J. B. Murphey

USDA Sedimentation Laboratory
Oxford, Mississippi

April 1981

Prepared for
US Army Corps of Engineers, Vicksburg District
Vicksburg, Mississippi

Under
Section 32 Program, Work Unit 7

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STREAM CHANNEL STABILITY.

APPENDIX E.

Geomorphic Controls of Channel Stability.

Project Objective 5

by

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and

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PREFACE

This process-oriented study was organized to investigate three complementary aspects of channel stability including (a) the nature of channel failure processes; (b) the influences of valley-fill depositional units on these processes and (c) the properties and distributions of the valley-fill units. The study was process oriented to couple easily with complementary studies and to ensure that results have maximum utility for use in adjacent areas. The study was implemented and has been reported as four units including (a), the near-surface geologic investigation, ~~(b)~~ the investigation of the late-Quaternary valley-fill deposits, ~~(c)~~ the channel stability investigation and (d) the channel morphometric investigations,

The properties and distributions of the valley-fill units directly and indirectly influence the nature of channel failure processes. Although gravity-induced failure is the most frequent form of present-day bank instability, the type of gravity failure is dependent upon the properties of the valley-fill units. Both depositional and weathering properties influence the type of failure. The valley-fill units indirectly influence bank stability through their control of groundwater movement and the development of unusually large seepage forces at point-locations along the channels. Bed instability has primarily resulted from upstream migration of knickpoints and the rate of knickpoint migration has been affected by (valley-fill) unit controls. ~~The~~ present drainage systems in the study area are immature; channel morphometry has not adjusted at this time to the new flow regime resultant from cultural and natural changes. Changes will occur with time and the conditions of channel stability or instability will evolve from site specific influences, valley-fill unit controls and system characteristics.

The distributions and properties of the valley-fill units and their ^{14}C ages reflect paleoclimatic conditions and base level fluctuations. This finding enhances the predictive capabilities for extrapolating results from the study area to other locations subjected to similar late-Quaternary controls. The near-surface geologic investigation has established, however, that the presently mapped near-surface stratigraphy is not accurate. These geologic materials are source materials for the valley-fill deposits and the uncertainty concerning the nature and distribution of

the near-surface geologic units limits full development of predictive capabilities. The subsurface investigations have identified a paleosurface (buried surface) which controls groundwater movement. The paleosurface is not congruent with surface watershed definition, raising the possibility of groundwater transfer between watersheds.

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CONVERSION FACTORS, U.S. CUSTOMARY TO METRIC (SI) AND METRIC (SI) TO U.S. CUSTOMARY UNITS OF MEASUREMENT 1/

Units of measurement used in this report can be converted as follows:

To convert	To	Multiply by
mils (mil)	micron (μm)	25.4
inches (in)	millimeters (mm)	25.4
feet (ft)	meters (m)	0.305
yards (yd)	meters (m)	0.914
miles (miles)	kilometers (km)	1.61
inches per hour (in/hr)	millimeters per hour (mm/hr)	25.4
feet per second (ft/sec)	meters per second (m/sec)	0.305
square inches (sq in)	square millimeters (mm^2)	645.
square feet (sq ft)	square meters (m^2)	0.093
square yards (sq yd)	square meters (m^2)	0.836
square miles (sq miles)	square kilometers (km^2)	2.59
acres (acre)	hectares (ha)	0.405
acres (acre)	square meters (m^2)	4,050.
cubic inches (cu in)	cubic millimeters (mm^3)	16,400.
cubic feet (cu ft)	cubic meters (m^3)	0.0283
cubic yards (cu yd)	cubic meters (m^3)	0.765
cubic feet per second (cfs)	cubic meters per second (cms)	0.0283
pounds (lb) mass	grams (g)	454.
pounds (lb) mass	kilograms (kg)	0.453
tons (ton) mass	kilograms (kg)	907.
pounds force (lbf)	newtons (N)	4.45
kilogram force (kgf)	newtons (N)	9.81
foot pound force (ft lbf)	joules (J)	1.36
pounds force per square foot (psf)	pascals (Pa)	47.9
pounds force per square inch (psi)	kilopascals (kPa)	6.89
pounds mass per square foot (lb/sq ft)	kilograms per square meter (kg/m^2)	4.88
U.S. gallons (gal)	liters (L)	3.79
quart (qt)	liters (L)	0.946
acre-feet (acre-ft)	cubic meters (m^3)	1,230.
degrees (angular)	radians (rad)	0.0175
degrees Fahrenheit (F)	degrees Celsius (C) 2/	0.555

2/ To obtain Celsius (C) readings from Fahrenheit (F) readings, use the following formula: C = 0.555 (F-32).

Metric (SI) to U.S. Customary

To convert	To	Multiply by
micron (µm)	mils (mil)	0.0394
millimeters (mm)	inches (in)	0.0394
meters (m)	feet (ft)	3.28
meters (m)	yards (yd)	1.09
kilometers (km)	miles (miles)	0.621
millimeters per hour (mm/hr)	inches per hour (in/hr)	0.0394
meters per second (m/sec)	feet per second (ft/sec)	3.28
square millimeters (mm^2)	square inches (sq in)	0.00155
square meters (m^2)	square feet (sq ft)	10.8
square meters (m^2)	square yards (sq yd)	1.20
square kilometers (km^2)	square miles (sq miles)	0.386
hectares (ha)	acres (acre)	2.47
square meters (m^2)	acres (acre)	0.000247
cubic millimeters (mm^3)	cubic inches (cu in)	0.0000610
cubic meters (m^3)	cubic feet (cu ft)	35.3
cubic meters (m^3)	cubic yards (cu yd)	1.31
cubic meters per second (cms)	cubic feet per second (cfs)	35.3
grams (g)	pounds (lb) mass	0.00220
kilograms (kg)	pounds (lb) mass	2.20
kilograms (kg)	tons (ton) mass	0.00110
newtons (N)	pounds force (lbf)	0.225
newtons (N)	kilogram force (kgf)	0.102
joules (J)	foot pound force (ft lbf)	0.738
pascals (Pa)	pounds force per square foot (psf)	0.0209
kilopascals (kPa)	pounds force per square inch (psi)	0.145
kilograms per square meter (kg/m^2)	pounds mass per square foot lb/sq ft)	0.205
liters (L)	U.S. gallons (gal)	0.264
liters (L)	quart (qt)	1.06
cubic meters (m^3)	acre-feet (acre-ft)	0.000811
radians (rad)	degrees (angular)	57.3
degrees Celsius (C)	degrees Fahrenheit (F)[3/]	1.8

1/ All conversion factors to three significant digits.

2/ To obtain Fahrenheit (F) readings from Celsius (C) readings, use the following formula: F = 1.8C + 32.

1 INTRODUCTION

Geomorphology is the science concerned with the nature and origin of the surface features of the Earth. Individual surface features are usually referred to as landforms and a series of landforms constitute a landscape. Inherently, most landforms have been produced by either erosional or depositional processes, or by both. Alternately, some are the product of volcanic or tectonic activity. Landforms within any present-day landscape, however, have been altered by subsequent less-intense processes of deposition and/or erosion and by weathering processes. Rates of landform change in response to changing environmental conditions are not constant but vary between landforms and, for a given landform, vary with its relative position in the landscape.

This rather simplistic introduction belies the complexities involved in integrating this applied geomorphic investigation into the overall study of stream channel stability. Two general conditions are critical in order to maximize the usefulness of results. These two are the line of inquiry and the definition of the system and system components (the landforms and landscapes).

1.1 LINES OF INQUIRY

Higgins (1975) identified three lines of geomorphic inquiry. These are:

a. the description of existing landforms and landscapes,
b. the changes in landforms and landscapes which progress through time,
c. the identification and quantification of processes responsible for formation and for modification of existing landforms and landscapes.

This latter line of inquiry, termed process or dynamic geomorphology, differs from the preceding two both in technique and in application. The first two are primarily morphometric and frequently tacitly assume a space-time continuum. Landform identification is based primarily on morphometric criteria. Results from such studies are not readily usable in other areas. Process geomorphology assumes no such continuum. It encompasses morphometry and, more significantly, adds a depth component to the study system. Ruhe (1975) refers to this third dimension as surficial geology. The depth dimension pertinent to any given process geomorphic

study is axiomatically established as that depth necessary to fully evaluate pertinent processes of formation and of modification. Identification of dominant process controls of landform formation, also referred to as forcing functions, is inherent in this approach and such identification facilitates extrapolation of results to areas outside of the study area but subjected to the same forcing functions. Landforms are identified and classified as process units, based on the dominant process controls. Process geomorphology, thus, has many advantages for this study; it has been employed whenever possible. Advantages are:

a. the ease of coupling with standard engineering-type activities,
b. the ease of coupling with process-based simulation models,
c. continuity with the processes influencing channel bed and bank failure,
d. it is system oriented.

1.2 DEFINITIONS OF THE GEOMORPHIC SYSTEM

The fluvial system is the dominant feature common to both the channel stability and geomorphic aspects of this study. An idealized fluvial system discussed by Schumm (1977) is presented in Fig. 1. For this study, we assume the geomorphic system can be defined in relation to the (idealized) fluvial system. Landscapes and landforms within this system have not been formally defined at this time. Rather, we have classified units based on formation-controlling and modifying processes. Ultimately landforms will be identified but these will be based on process units; a morphometric classification is unacceptable due to the subjectiveness of landform definition and the poor interpretative value of landforms identified by morphometric properties only.

Many of the process units are relict elements, produced by forcing functions (dominant processes) different from those of today. Examples of relict elements are:

a. the early-Holocene valley-fill units (discussed in section 4.2 of this Appendix),
b. the fragipan horizon in the loess soils formed by pre-Peoria weathering (Buntley et al., 1977),
c. the variation in drainage density related to landscape age (Ruhe, 1969).

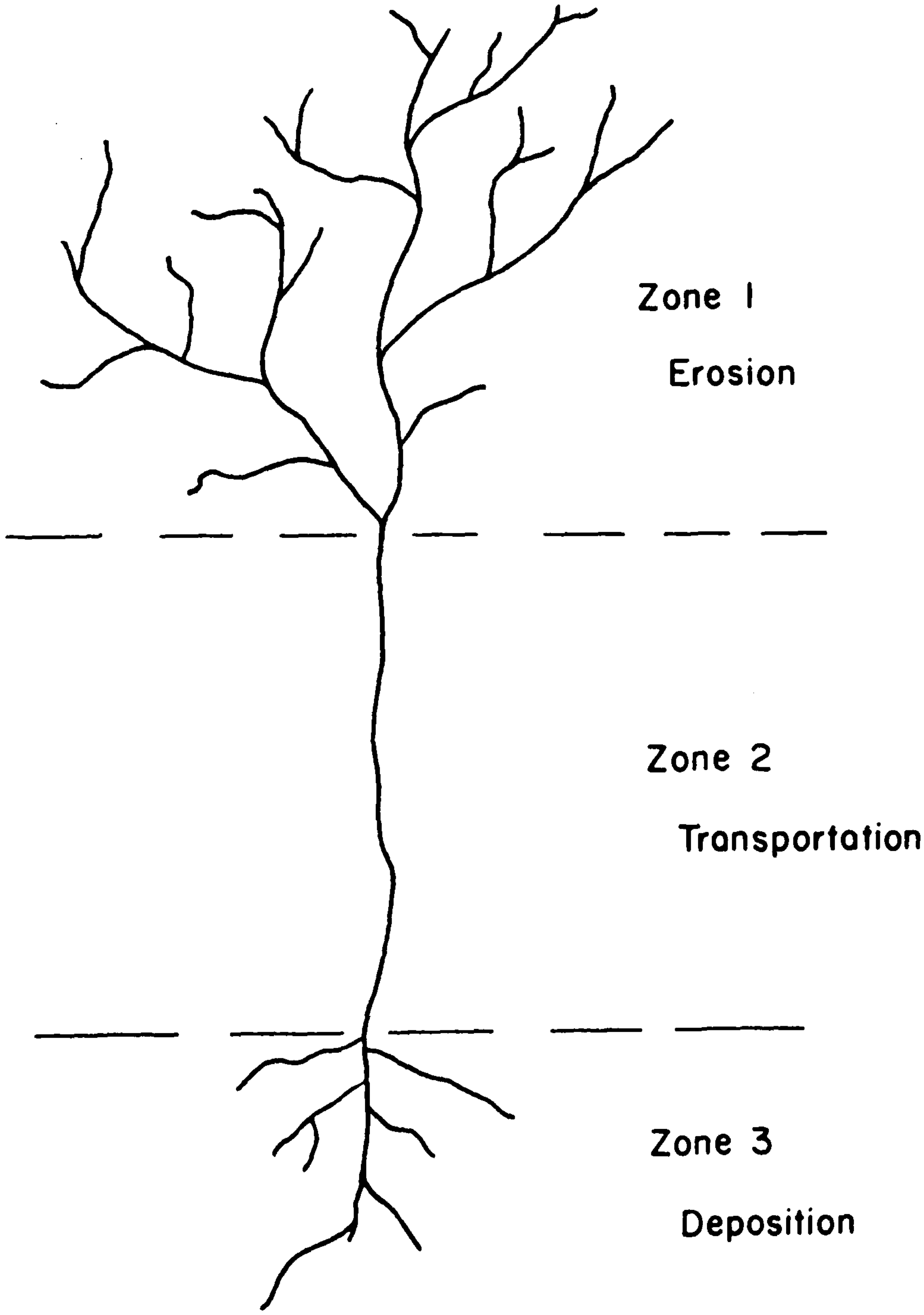

Figure 1 Idealized fluvial system (after Schumm, 1977).

Figure 2 is an additional example illustrating relict elements associated with the drainage net. Tributary B has a well-developed alluvial flood plain whereas tributary A does not. Tributary B is evidently older than the adjacent tributary. Tributary C also has no flood plain along its present path. It was evidently diverted from its earlier path at D. Such relict elements may be time-variant or time invariant for the time span implicit in the investigation and they may or may not be pertinent to the objectives of the investigation.

The assemblage of relict and present-day elements in any given system is, of course, pertinent to current processes characteristic of the system. The representativeness of any given system, or data pertinent to a system, for characterizing a region depends upon the distribution of relict and present-day elements within the system relative to that of the region. (Clarke, 1977, discusses this problem of representative basins.) As noted previously, relict elements were produced by forcing functions (dominant process controls) which characterized past ages. Inherently, the present distribution of relict elements was established by the distribution of (past) forcing functions. These (past) forcing functions varied drastically during the Quaternary Period and similitude with present conditions is unlikely. Identification of forcing functions and definition of their distribution is prerequisite to maximum predictive capabilities.

1.3. DEFINITIONS OF THE FLUVIAL SYSTEM

As noted previously, the fluvial system is common to both aspects of this study, to both the geomorphic system and to channel stability. The following definitions are an attempt to develop terminology which (a) describes channel stability in relation to overall system characteristics and (b) can be used interchangeably for both geomorphic and channel stability investigations.

1.3.1 Channel Stability

By themselves, stable and unstable are nebulous, relative terms when applied to channels. All channels are subject to changes which are evaluated as acceptable or unacceptable based on socio-economic and time criteria. If the rate or magnitude of change is unacceptable, the channels are classified as unstable. This classification of stable versus unstable channels is, in essence, independent of stream system characteristics.

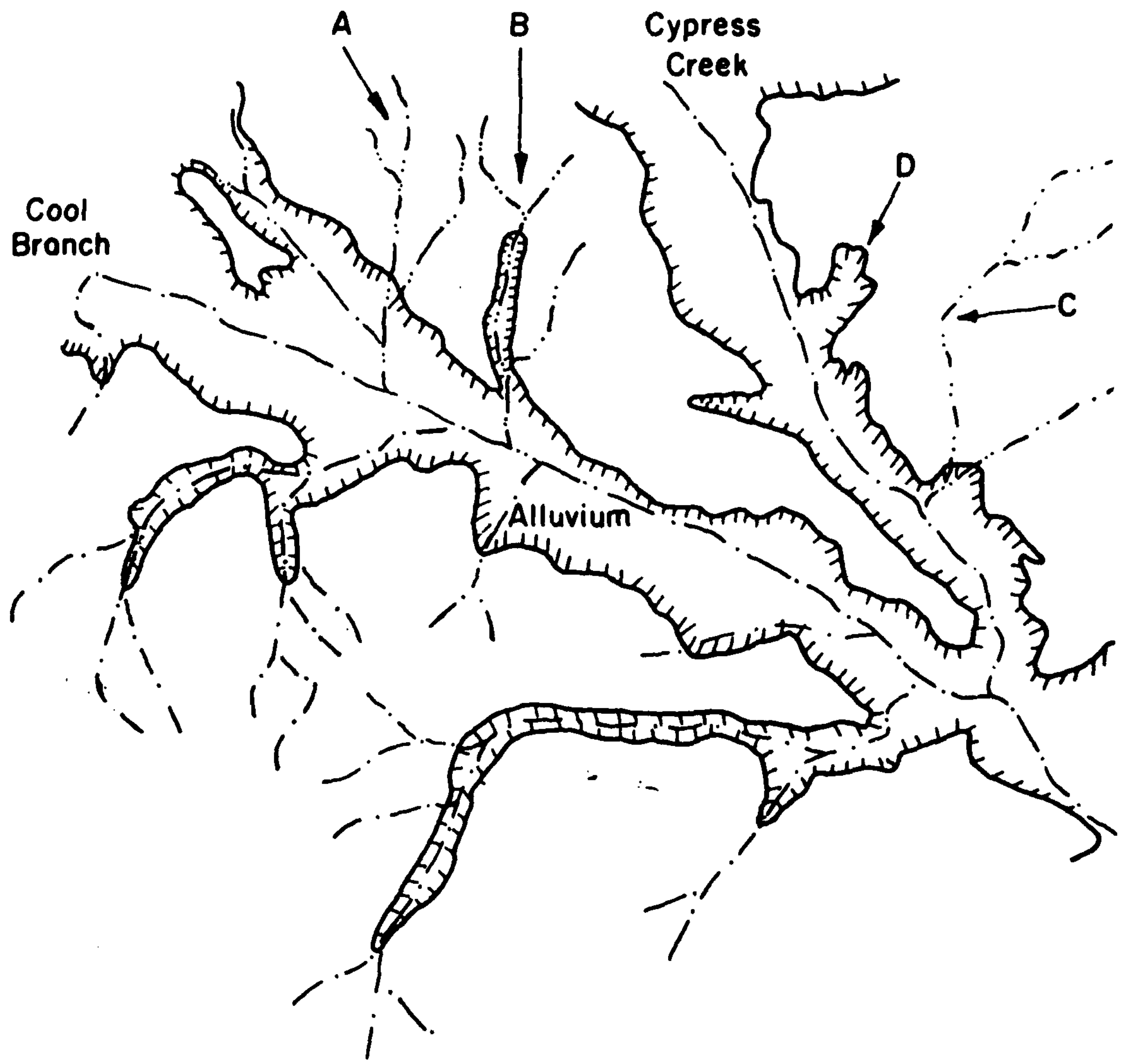

Figure 2 Alignment of tributary drainage with alluvial deposits, Cypress Creek (from Sheet 30, Huddleston et al., 1978).

1.3.2 Idealized Stream (Fluvial) System

Schumm (1977) describes an idealized fluvial system (Fig. 1) which has great utility for channel stability evaluations. In simple form, this idealized system has three zones. The headward-most zone, Zone 1, is the area of sediment and water production. By definition, this is a zone of erosion and temporary storage of sediment. The middle zone, Zone 2, is the transfer zone. Channels in this zone are at grade if sediment input equals sediment output. The lowermost zone, Zone 3, is the area of deposition. Aggradation occurs in this zone. Thus, both aggradation and degradation will occur simultaneously in any one complete system. Channels in the transfer zone will be at grade for a stable system but such channels may be termed unstable based on socio-economic criteria. Several conditions should be noted for this idealized system:

a. most study watersheds are not complete systems,

b. zone boundaries are probably stage dependent,

c. zone boundaries become less well defined as the size of the system is reduced, that is, as variables extrinsic to the system become relatively more significant.

1.3.3 System Changes

Inherently, the system discussed by Schumm (1977) has a high degree of interdependence between the zones. Changes in either or both sediment and water production and/or routing will induce changes in Zones 2 and 3. Additionally, changes within the system which alter backwater levels and/or peak flow synchroneity may effect changes throughout the system. Kellerhals et al. (1979) discuss such morphological effects of flow diversion. The forcing function (the dominant control) of such changes may be either intrinsic or extrinsic and may effect changes within existing zones or may cause the boundaries between individual zones to change. An extreme example of this latter type of change is that produced by the concurrent paleoclimatic and base level change at the Holocene-Wisconsin (time) boundary. During late-Wisconsin times, many of the present Bluff Area valleys were in Zone 1. Due to vast amounts of glacial debris being flushed down the Mississippi and Ohio Rivers and concurrent rises in sea level from glacial thaw, the Bluff Area valleys quickly changed to Zone 3. Other forcing functions include land use changes, channelization and water-handling structures which cause peak flow asynchronism.

Secondary systems are frequently imposed upon the simple idealized system. Two types of secondary systems have been observed. Excessive sediment production in Zone 1 may form a large sediment wave. Such waves, equivalent to a micro Zone 3, move downstream effecting channel changes. The second type involves knickpoint migration upstream. The knickpoints, equivalent to a micro Zone 1, similarly effect reach changes; but such changes migrate upstream (the large sediment waves move downstream), ultimately resulting in excessive sediment production. This type of complex response is typical in many Bluff Area streams.

1.3.4 Stability Classes

The classes of instability are an attempt to more-definitively classify channel changes. This classification also has utility for channel improvement activities. System instability is typified by changes, particularly bed elevation changes, throughout the system, Zones 1, 2 and 3. The system must be modified before bank stability can be achieved. Local bank protection measures will only transfer problems. This system instability represents a total imbalance between hydraulic erosive forces and bank material strength. Point instability, on the other hand, typifies a relatively stable system. The channel bed is stable and bank failure results from atypical local conditions. This type of failure can be alleviated by standard bank protection measures, if such is deemed necessary. Reach instability represents the middle area between the two extremes. The system is marginally stable; some reaches are stable and some are not. If the positions of the stable and unstable reaches are time invariant with respect to the fluvial system, noted as static reach instability, failure most probably is the result of channel morphometric conditions or relatively weak bed or bank materials. Failure mechanisms must be ascertained to evaluate (a) potential rate of change and (b) the probability of natural healing. Unstable reaches which migrate through the fluvial system with time, termed dynamic reach instability, typify complex systems and must be evaluated accordingly. Knickpoint migration is a particularly detrimental type of dynamic instability in that it may result in both static reach instability downstream of the knickpoint and ultimately excessive sediment production from Zone 1 as the knickpoint moves upstream. Such knickpoints are obviously detrimental to long-term stability and must be controlled as the first phase of any stabilization program.

RESEARCH OBJECTIVES AND ORGANIZATION

The objectives of this study are:

a. to identify the distributions and properties of stratigraphic units within the geologically-recent valley alluvial deposits,

b. to establish associations between bank instability and the properties of the stratigraphic units and their sequences,

c. to develop predictive capabilities for defining the sequence of stratigraphic units within the alluvial valley deposits.

Objectives a. and b. are self-evident and require no further discussion. Objective c. involves details and activities not explicit in this statement. In essence, this objective describes a geomorphic application which is additional to that of describing present landforms or landscapes or of evaluating their influence on specific, current processes (problems). This additional application is that the landscape of a given study area can be used to predict landforms in other areas, provided such areas have been formed by the same process controls. Much of the discussion and many of the definitions in the Introduction pertain to this objective. It requires subsurface information sufficient to satisfy data requirements for process geomorphic interpretation and this, in turn, requires subsurface information not only for the alluvial deposits but for the complete system.

This study has been organized into the following activities:

a. Near-surface geology (excluding valley-fill deposits) - including (1) field observation by outcrop and drilling, and (2) sample characterization.

b. Valley-fill deposits - including (1) field observation by outcrop and drilling and (2) sample characterization.

c. Channel Stability - including (1) field observation of the types of failure and the association of failure type with stratigrphic units and (2) photographic interpretation to establish channel conditions and changes thereof, using the ASCS aerial photographic record (about the last 40 years).

Wood samples for ^{14}C analysis and identification have been collected whenever possible to define time sequences, facilitating comparison of the valley-fill stratigraphic record with the paleoclimatic and other forcing function records. Wood samples collected but not analyzed are identified in Addendum 1. Most of these samples are too small for conventional analysis.

Results are presented in Sections 3 through 5 in the same order as listed above. For these results:

a. Failure rates for individual stratigraphic units have not been quantified due to the lack of hydraulic data. Such data will be available in the near future and quantification will be attempted.

b. More time than anticipated was devoted to near-surface geologic investigation. This resulted from our initial finding of serious errors in the presently accepted stratigraphic column, discussed in section 3.

c. Terrace and upland loess (soil) profiles have not been evaluated due to time constraints resultant from b. Such studies have been initiated.

d. Data limitations resultant from b. and c. prevent synthesis of the geomorphic system as described in the Introduction. These thoughts have been retained in the Introduction to develop constructive dialogue with interested personnel. Process controls (forcing functions) and process units have been identified for the valley-fill deposits and are discussed in sections 4 and 5.

3 NEAR-SURFACE GEOLOGIC INVESTIGATION

These results have been separated into two units, one describing the detailed investigation in the study watersheds, Panola County, and a second summarizing the survey-type investigation in the Yazoo-Little Tallahatchie watershed of north Mississippi.

3.1 DETAILED INVESTIGATION OF THE STUDY WATERSHEDS[1/]

3.1.1 Introduction

The study area includes four watersheds in the southeast quarter of Panola County, northern Mississippi. This area is within the Coastal Plain Physiographic Province, with the western two-thirds in the Loess or Bluff Hills Subprovince and the eastern one-third in the North Central Hills Subprovince. Loess caps all interfluves but thins rapidly from west to east; Holocene alluvial deposits are present in all valleys. Drainage is westerly to the Mississippi alluvial valley via the Tallahatchie River for Hotophia Creek and via the Yocona River for Peters Creek and its tributaries including Johnson, Goodwin and Long Creeks (Fig. 3).

The generalized section of stratigraphic units for Panola County is summarized in Table 1 (Vestal, 1956). This generalized section agrees with those of surrounding counties. The Meridian formation (basal Claiborne) and the Ackerman formation (upper Wilcox) were both included in the sections for Lafayette (Attaya, 1951) and Yalobusha (Turner, 1952) Counties, east and southeast of Panola County, respectively. However, Brown (1947) and Lang and Boswell (1960) considered the Meridian to be a member of the Tallahatta formation. Additionally, Priddy (1942) divided both the Zilpha and Winona formations into upper and lower divisions. The age of the gravel unit is the source of some disagreement in that Fisk (1944) and Kolb et al. (1968) both identified this unit as basal terrace deposits of Pleistocene age whereas a Pliocene age was accepted by Vestal (1956) who considered the gravels to be units of the Citronelle formation.

Field identification of individual formations in northern Mississippi has been a major problem due to (a) the loess veneer, (b) the absence of diagnostic marker beds, and (c) the similar nature of the numerous sand

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1/ Most of this material is included in an article which has been accepted for publication in Southeastern Geology.

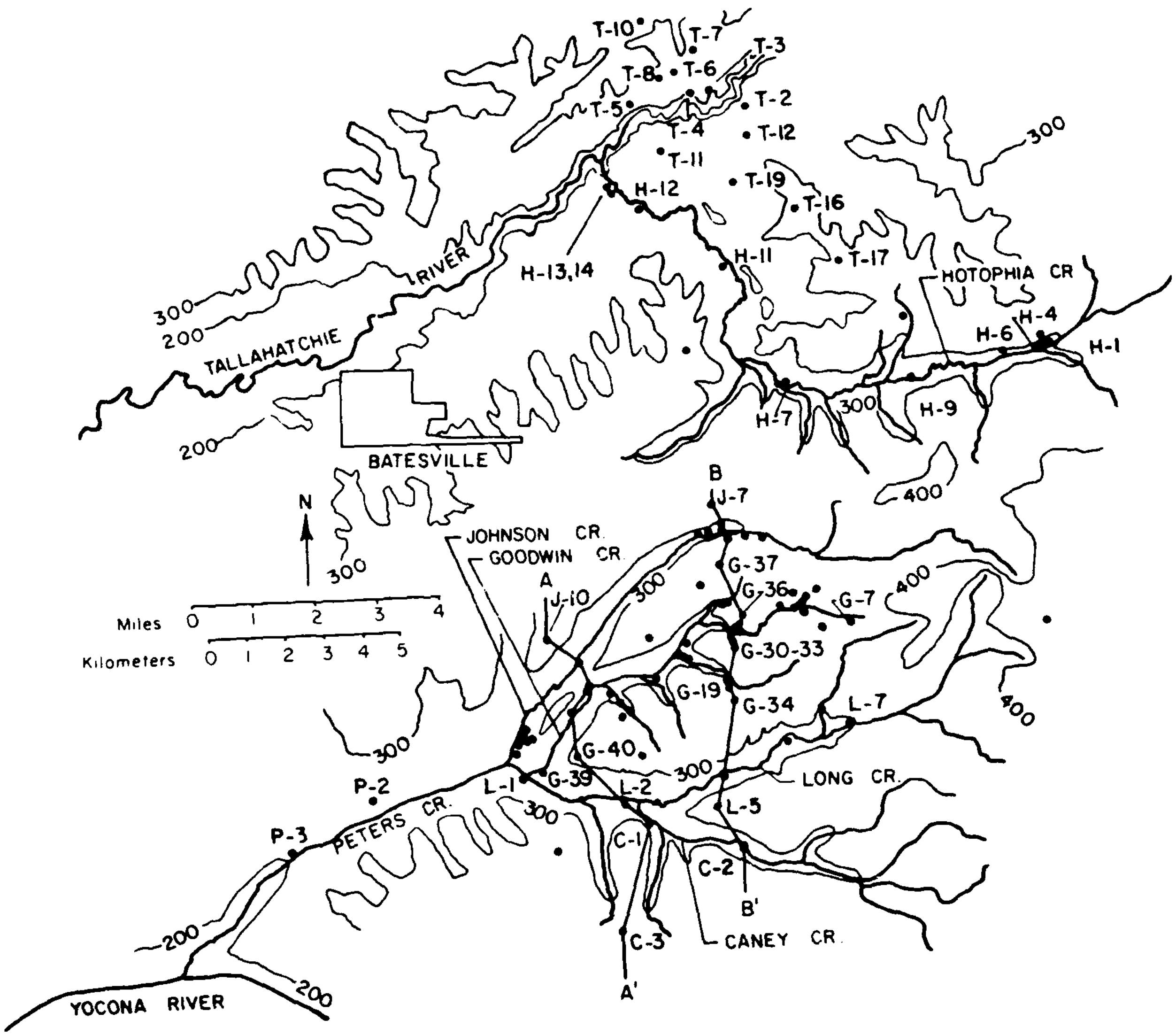

Figure 3 Location of exploratory holes in intensive study area, Panola County, Mississippi.

SYSTEM	SERIES	FORMATION	MEMBER
QUATERNARY	HOLOCENE	RECENT ALLUVIUM	
	PLEISTOCENE	LOESS	
TERTIARY	PLIOCENE	CITRONELLE	
	EOCENE-CLAIBORNE	KOSCIUSKO	
		ZILPHA	
		WINONA	
		TALLAHATTA	NESHOBA
			BASIC CITY

Table 1 Generalized section of stratigraphic units, Panola County, Mississippi (after Vestal, 1956).

exposures which either directly underlie the loess cap or are exposed at the surface. These sand units are presently mapped as Eocene formations but were originally considered by Hilgard (1860) to be Quaternary in age. He named these materials the Orange Sand formation. Logan (1907) renamed these sands Lafayette and included surficial gravels, conglomerates, ironstones, plastic clays and silts within this formation. He also considered this unit to be Quaternary in age. Since Logan's report, however, these surficial materials have been considered to be Eocene formations (Lowe, 1913; Attaya, 1951; Turner, 1952; Vestal, 1956).

Five of these formations concern this report -- the Citronelle, Kosciusko, Zilpha, Winona, and Tallahatta. Characteristic properties as reported by Vestal (1956) are:

Citronelle formation--sand, sandstone, gravel, and clay.

The sand is coarse to fine, cross-bedded to the southeast, and cemented in places. Gravel is sparse and occurs as stringers to thin beds. Clay is present as lenses or is disseminated in the sand phase as a minor component.

Kosciusko formation--sand, sandstone and reworked clay.

Sand is fine to coarse and has variable colors ranging from light gray to chocolate or red-brown. Clays are pink, yellowish or white and occur as balls, nodules, stringers, or as matrix within the sands.

Zilpha formation--clay, sandy silt, lignite, sandstone and siltstone.

The fine sediments are shalelike, carbonaceous and brown to black when moist but dry to a gray color. They contain marcasite concretions and have a sulfide smell. They are layered and have laminae of micaceous silt to fine sand. The sands are fine, carbonaceous, gray to black, micaceous and have a sulfide smell.

Tallahatta formation--shale, clay, sand, silt, sandstone and siltstone.

The Neshoba member is composed of clean to argillaceous fine sand and is usually yellow to gray with some red to brown staining. Clay is present as matrix material, laminae, stringers or thin beds. This member is frequently micaceous and occasionally cemented. The Basic City member is shalelike to clayey, usually

light colored but occasionally brown to red, micaceous, and has scattered thin seams of organic material. Outcrops of this member are frequently cemented.

The Winona formation was not positively identified or described by Vestal for Panola County. Priddy (1942) described it in Tallahatchie County as follows:

Winona formation--sand, silt, clay, and claystone.

> This formation is slightly to very glauconitic, micaceous to very micaceous, carbonaceous, and has variable colors ranging from grayish-tan to greenish-brown to brownish-black. Clay is frequently present as thin stringers, laminae or beds. Outcrops oxidize rapidly to bright red to brown colors.

3.1.2 Methods And Materials

One hundred test holes were drilled in the study area (Fig. 3). Most of the holes were cased to minimize sample contamination, and relatively undisturbed cores were collected using either 1.5- or 3-inch diameter split spoons or 3-inch diameter Shelby tubes. Cemented materials were sampled using diamond core barrels. Most holes were sampled continuously but several of the deeper holes were skip drilled. Maximum sampling depth was 211 feet. The ground surface elevations of test holes were established by surveying.

Samples were collected and described at the drill site. This field description included color, texture, depositional and weathering features, the nature of the contacts, and other distinguishing characteristics. Blow counts were also recorded for split spoon samples. Color was described using the Munsell system. In addition, chemical characterization has been initiated for selected samples, including: pH; water-soluble calcium, magnesium, sodium and potassium; exchangeable calcium, magnesium, sodium and potassium; and extractable hydrogen, aluminum and iron. Chemical analyses followed the procedures of the Soil Conservation Service (1972). Analysis of this data is incomplete at this time.

We have examined formation exposures identified by Vestal (1956) and concur with his description of lithology. For purposes of continuity we have continued to use the formation names as proposed by Vestal (1956). However, we use these names only as lithologic unit names in reporting our results and identify such lithologic units by quotation marks. We disclaim

any implication of relative position within the generalized section for these lithologic units.

3.1.3 Results And Discussion

The three lithologic units relevant to a discussion of the stratigraphic column for the study area include the "Citronelle," "Tallahatta" including both the sandy phase "Neshoba" and clayey "Basic City" members, and the "Zilpha-Winona" facies complex. The "Zilpha" and "Winona" units are considered a facies complex due to their alternating occurrence (interfingering) with depth in most cores. Figs. 4 through 8 illustrate typical distributions of these units. Figs. 4 through 6 are profile sections along the long axes of Hotophia, Long, and Goodwin valleys respectively, whereas Figs. 7 and 8 are cross sections of the valleys. The hole spacings shown in these figures are straight-line distances between adjacent holes.

The typical sequence observed in these valleys, as illustrated in Figs. 4 through 6, is Holocene valley fill overlying either gravels or "Tallahatta" materials which in turn unconformably overlie the "Zilpha-Winona" facies complex. No pre-Holocene flood plain surfaces were identified. Iron-cemented sandstones frequently occur at the contact between the "Zilpha-Winona" complex and overlying materials. These sandstones are associated with abrupt textural changes. In several locations, valley-fill deposits directly overlie "Tallahatta" materials whereas at other locations typical "Tallahatta" materials occur as scattered bodies within or below the gravels and/or sands. These gravels may have been reworked following initial deposition and may thus be atypical "Citronelle." No gravels were observed at Hotophia Creek sites east of hole H-7 (Fig. 4). The presence of "Zilpha" material in the subsurface in the western part of the study area was expected since Vestal (1956) reported an exposure of this unit north of our study area and Kolb et al. (1968) reported its presence in the subsurface to the west. The presence of "Zilpha" material in the subsurface in the eastern part of our study area (east of hole H-7) was totally unexpected since Vestal (1956) identified outcrops in this area as Tallahatta.

Similar but more definitive sequences are presented in Figs. 7 and 8 for cross sections across Johnson, Goodwin and Long Creek valleys. Again "Tallahatta" materials occur as scattered bodies overlying the gravels, or

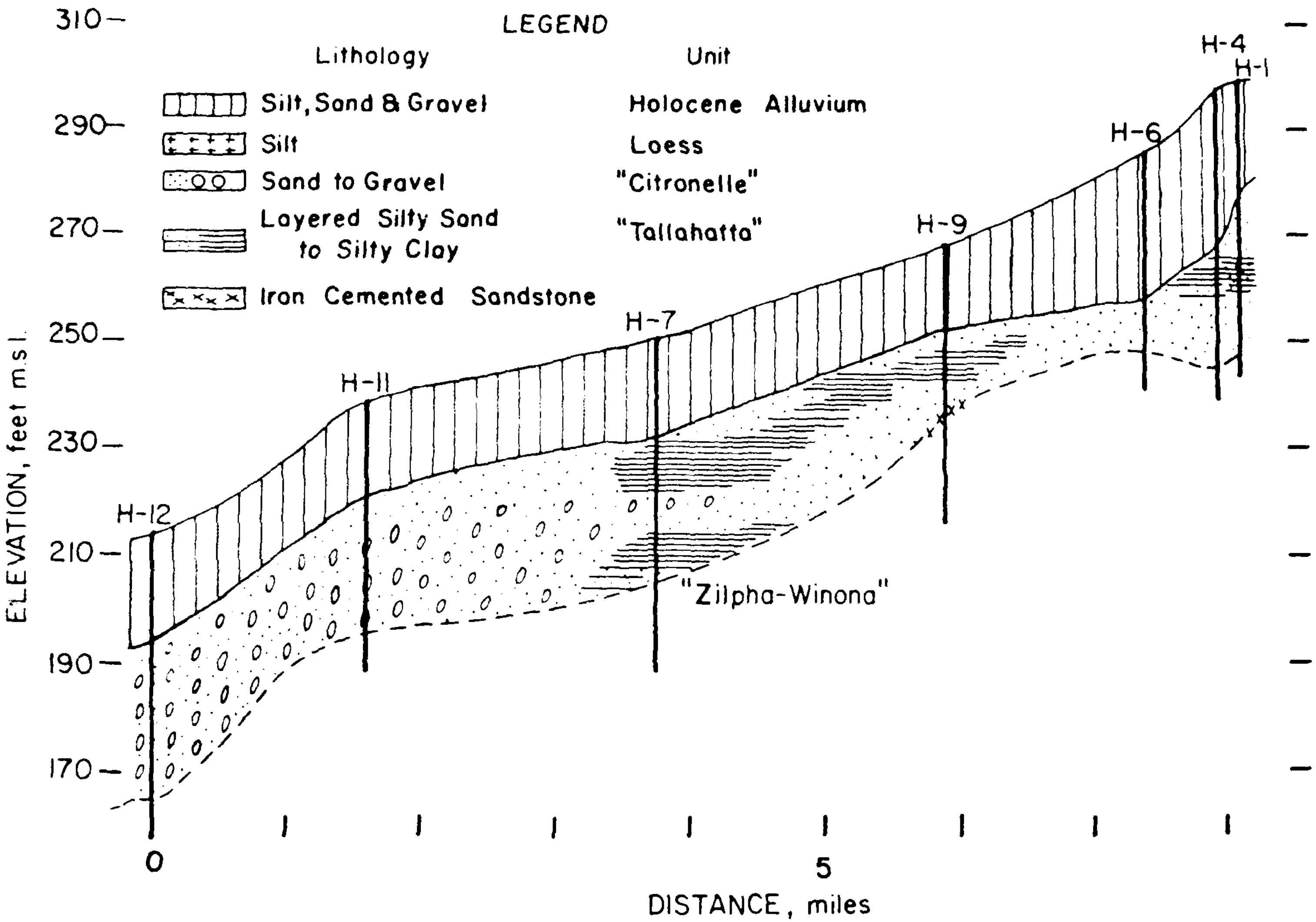

Figure 4 Profile section along Hotophia Creek valley.

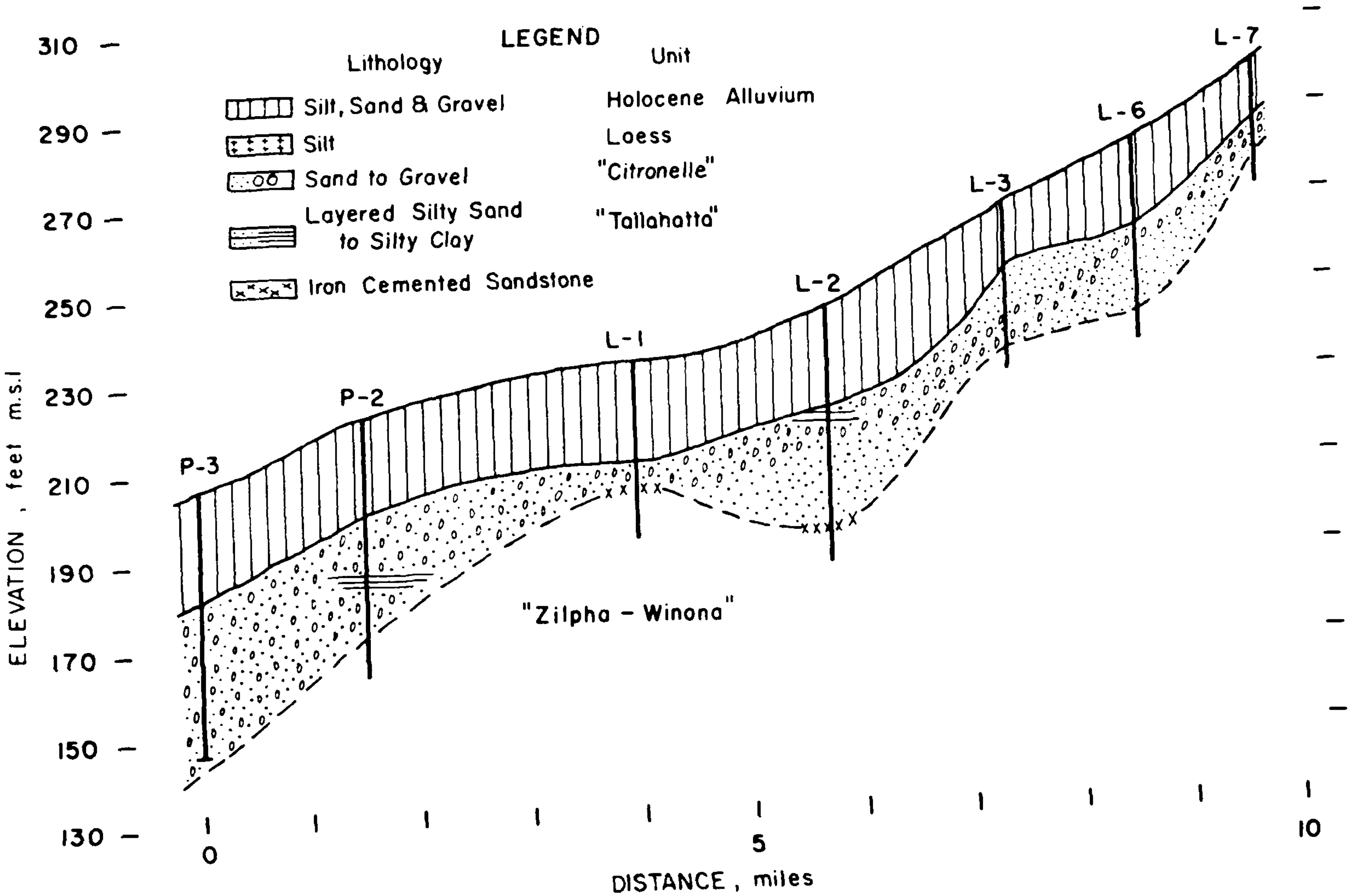

Figure 5 Profile section along Peters and Long Creek valleys.

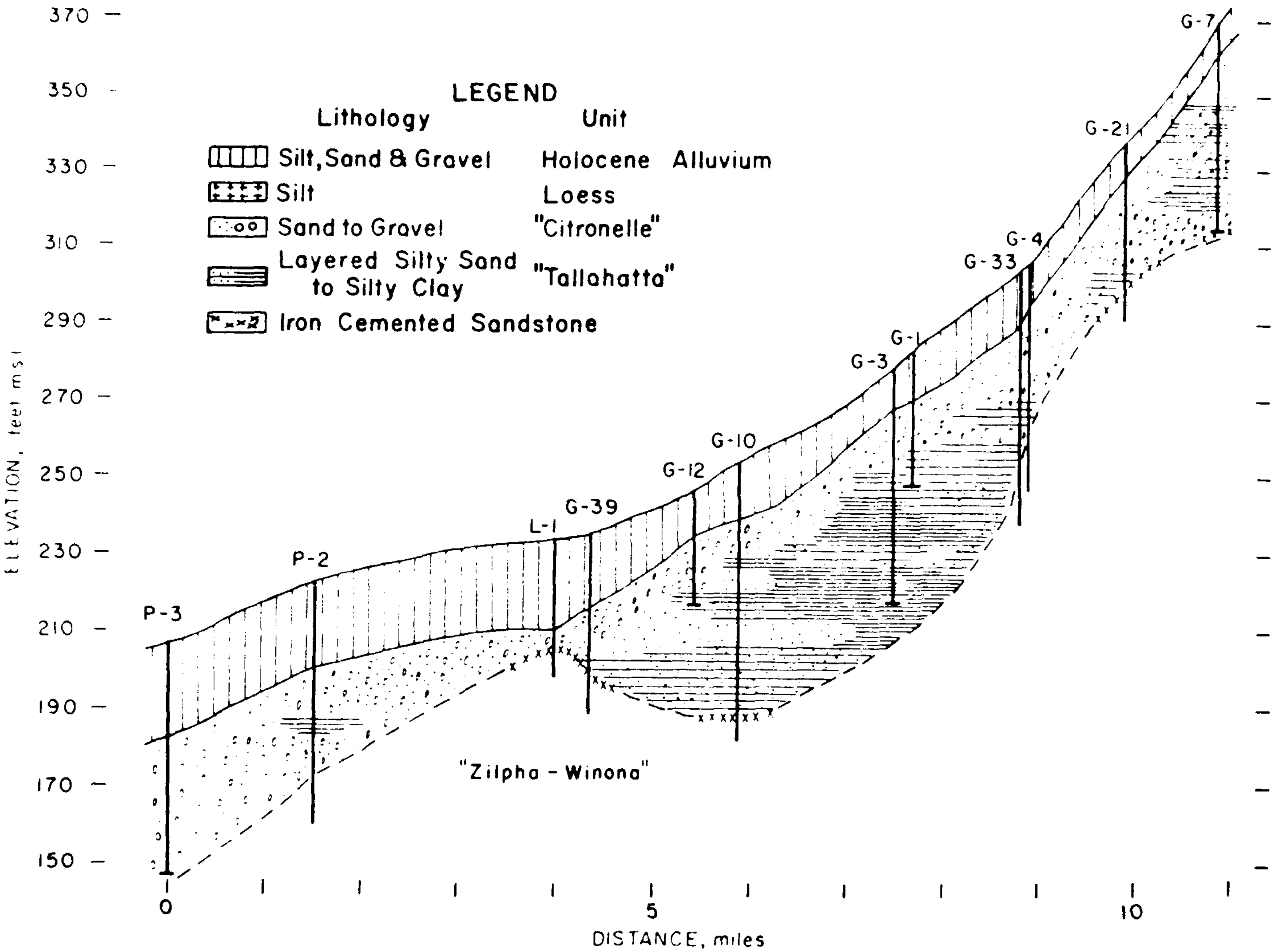

Figure 6 Profile section along Peters and Goodwin Creek valleys.

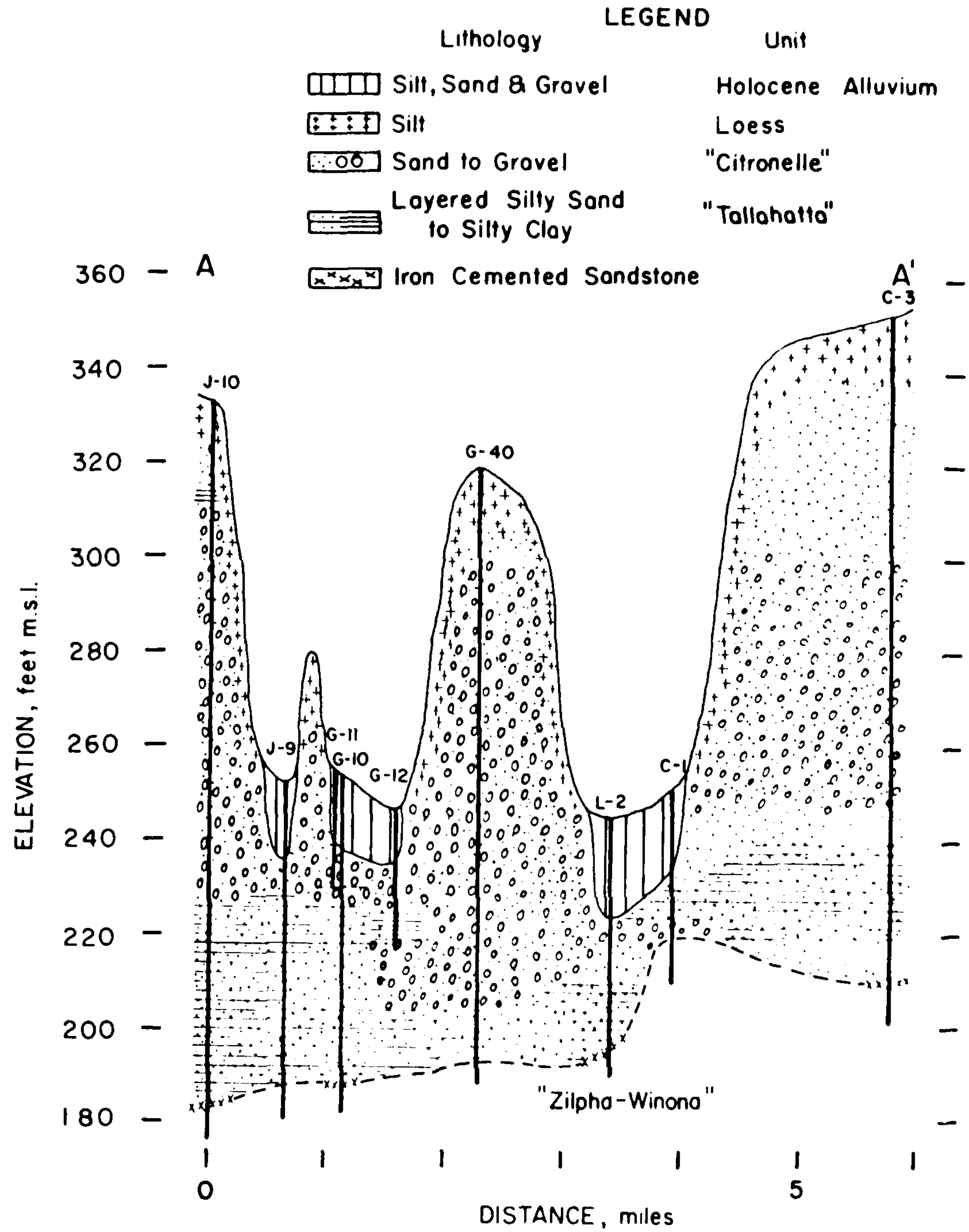

Figure 7 Cross section from hole J-10 to hole C-3 (A to A', Fig. 3).

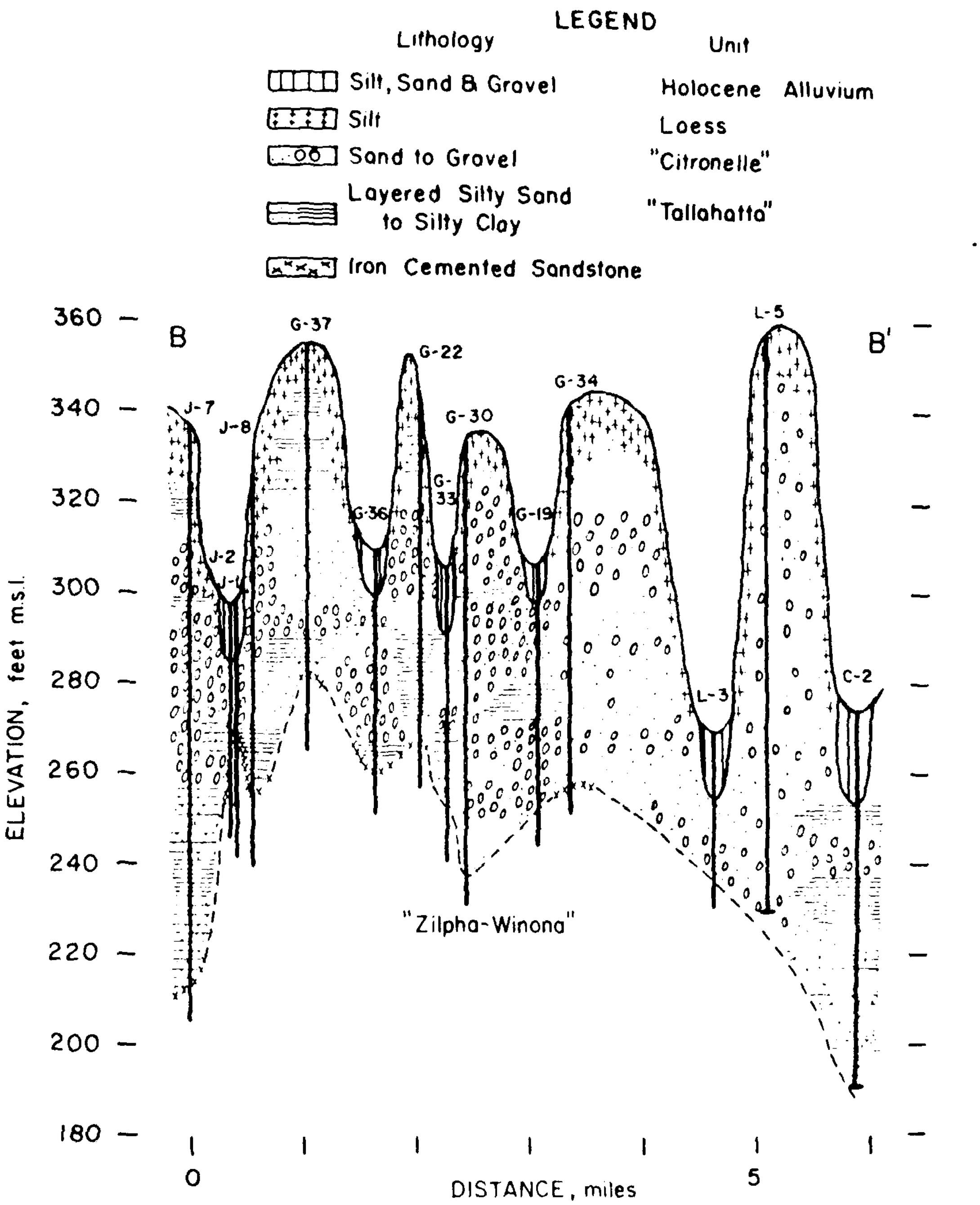

Figure 8 Cross section from hole J-7 to hole C-2 (B to B', Fig. 3).

in some cases within or below the gravels; both unconformably overlie the "Zilpha-Winona" facies complex. The gravels are typical "Citronelle," and the "Tallahatta" materials fit Vestal's (1956) description of this unit. The contact between the "Tallahatta" and the "Zilpha-Winona" complex materials, where present, is sharp with little or no weathering. This contact is characterized by an abrupt change of pH from 5 to 6 for the overlying "Tallahatta" to 3.5 or less for the underlying "Zilpha-Winona" complex. Similar abrupt changes at this contact characterize water soluble and extractable base data. Average chemical data for these two units are presented in Table 2. The single exception to the preceding chemical data concerns the few thin lignitic seams within the "Tallahatta." This lignitic material has chemical properties intermediate-with, or approaching, "Zilpha-Winona" type materials.

The relief on the "Zilpha-Winona" surface (Fig. 9) is enhanced by three dominant troughs; one conformable with Caney Creek valley, a second conformable with the Tallahatchie River valley and a third generally conformable with the Hotophia-Johnson divide. An additional incision is evident in Hotophia Valley near the Hotophia Creek-Tallahatchie River confluence. This incision generally follows the eastern edge of the gravel deposits and may have formed in response to gravel plugging of the original drainage. Additional definition of this paleosurface has been obtained by resistivity analysis (Fig. 10). The dissimilarity of the surface watershed and the top of the "Zilpha-Winona" complex is directly pertinent to ground-water conditions and water budgets for surface watersheds. From field observations, typical "Zilpha-Winona" samples were only slightly moist and "Zilpha-type" clayey materials were effectively dry. The overlying more permeable materials were generally saturated. This "Zilpha-Winona" surface functions as an aquiclude, perching ground-water and controlling subsurface hydrology.

The relative distributions of these lithologic units conflict with the presently accepted generalized section for Panola County. "Tallahatta" material was found to occur in association with the "Citronelle" gravels overlying "Zilpha-Winona" materials throughout the gravel-laden (western) part of our study area. In the gravel-free easternmost part, "Tallahatta" material was found superjacent to the "Zilpha-Winona" materials. This "Tallahatta" material is not in the proper position relative to either the

Table 2 Average chemical data for "Tallahatta" and "Zilpha-Winona" materials (a).

Analysis	"Tallahatta"	"Zilpha-Winona"
Extractable		
Iron	37 ppm	3,100 ppm
Aluminum	0.05 meq/100 g	4.19 meq/100 g
Hydrogen	0.06 meq/100 g	18.9 meq/100 g
Exchangeable		
Sodium	0.23 meq/100 g	0.04 meq/100 g
Potassium	0.21 meq/100 g	0.11 meq/100 g
Calcium	3.86 meq/100 g	3.60 meq/100 g
Magnesium	2.41 meq/100 g	0.44 meq/100 g
Water Soluble		
Sodium	<0.01 meq/100 g	0.02 meq/100 g
Potassium	<0.01 meq/100 g	<0.01 meq/100 g
Calcium	<0.01 meq/100 g	1.64 meq/100 g
Magnesium	<0.01 meq/100 g	4.66 meq/100 g
pH	5.50	2.00

(a) Average values for 10 samples each.

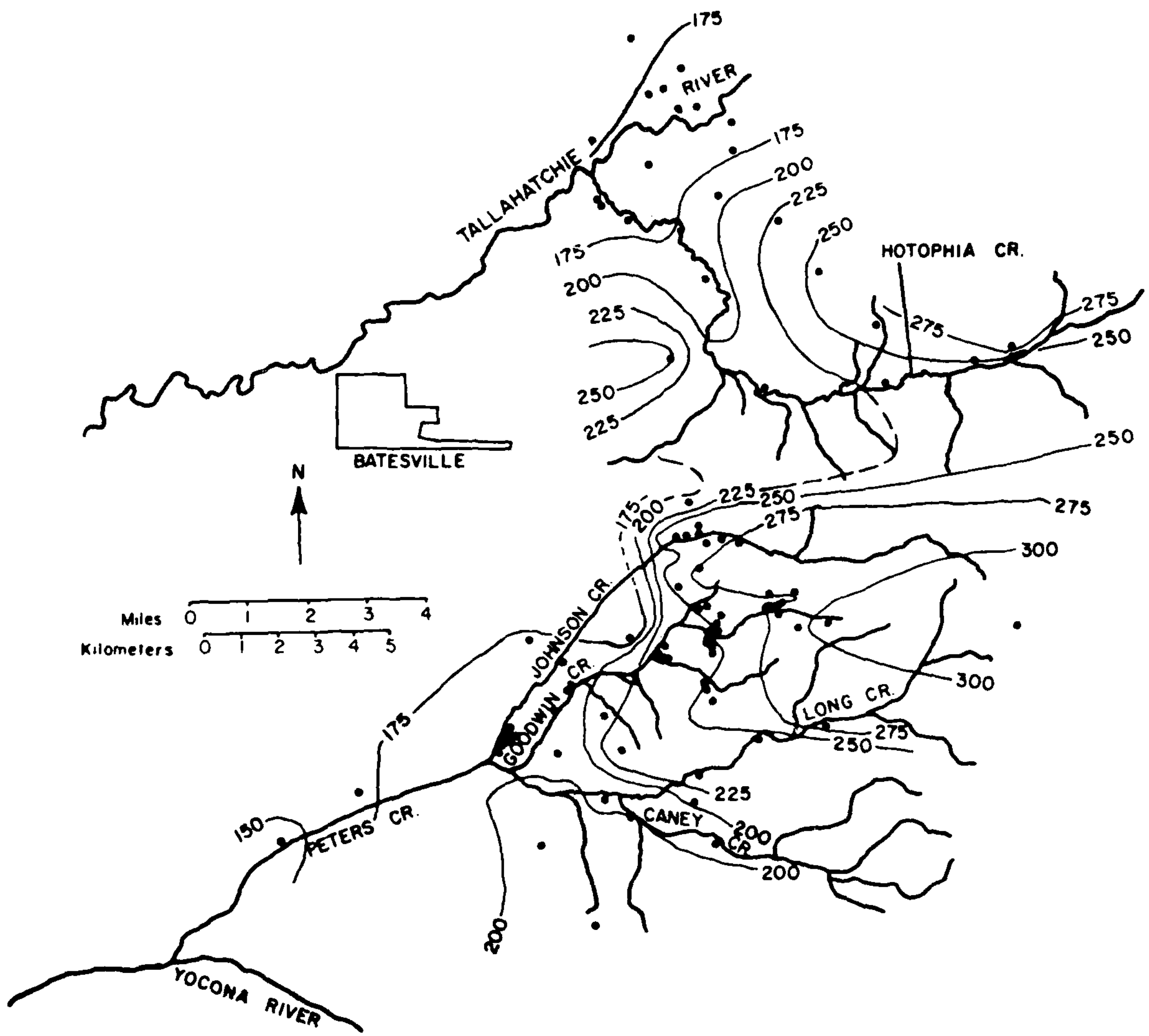

Figure 9 Surface of "Zilpha-Winona" complex, elevations in feet mean sea level.

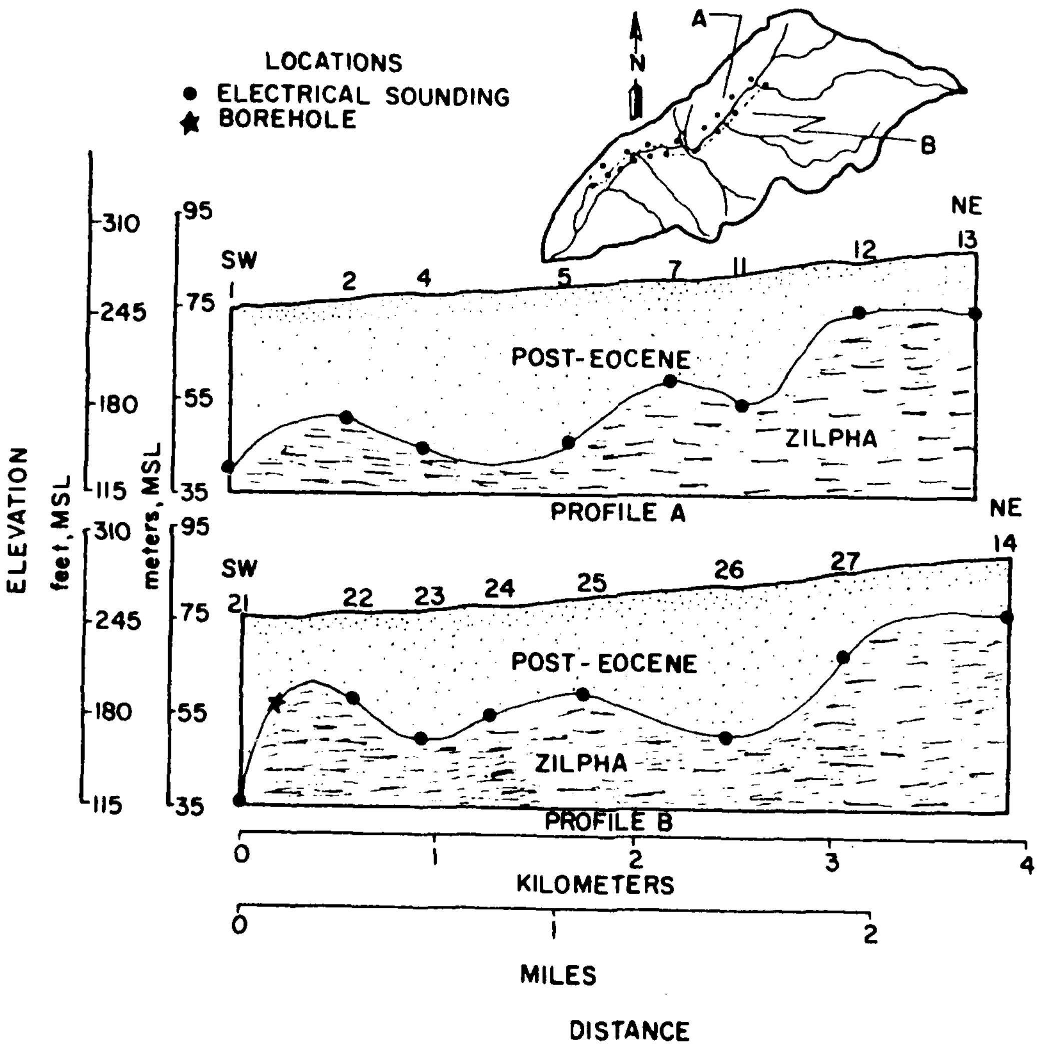

Figure 10a Surface of "Zilpha-Winona" complex under middle reaches of Goodwin Creek.

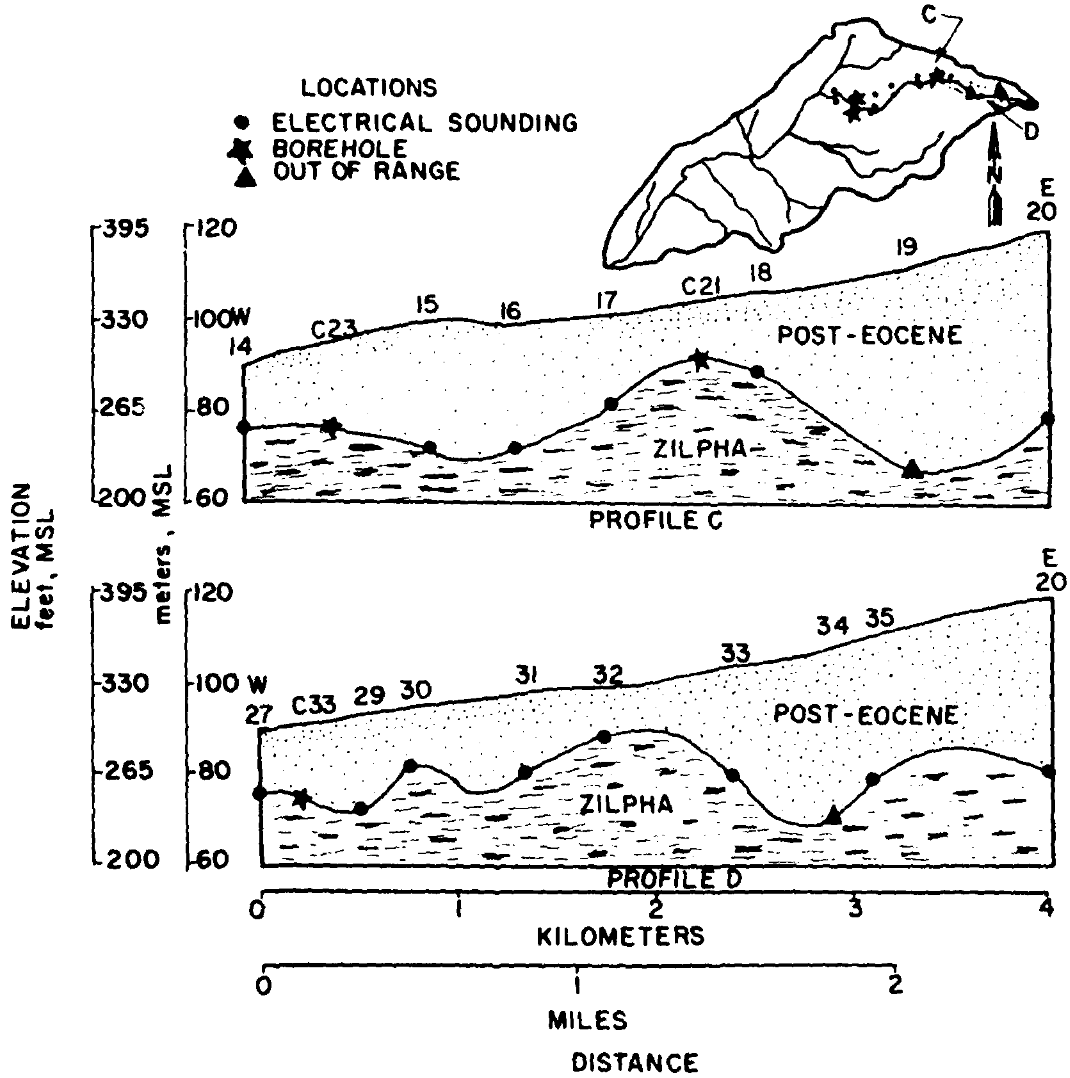

Figure 10b Surface of "Zilpha-Winona" complex under upper reaches of Goodwin Creek.

"Citronelle" or the "Zilpha-Winona" complex. Similarly, in the western half (approximately) of the study area, materials lithologically equivalent to the Koscuisko overlie "Citronelle" gravels which makes these materials also out of place.

We do not yet have enough data to justify an attempt at revising the standard section for this area of interest. Such a revision will evolve from a complete definition of the nature and distribution of the lithologic units and the configuration of the erosional surface, i.e., in our study area the erosional surface on the "Zilpha-Winona" complex. The relief on this surface (Figs. 9 and 10), the abrupt change in chemical properties of the materials at this contact (Table 2) and the occurrence of this surface east of the gravel deposits all suggest that this erosion surface has regional significance.

Complementary evidence for such a surface in the southern Mississippi Valley, however, is not well documented. Doering (1956) has reported one such surface underlying the coastal plain Citronelle (which may differ from the Mississippi Valley Citronelle). He reported that the Citronelle "is separated by an unconformity of regional importance from underlying beds which are generally lithologically different." Similar observations have been made by Hilgard (1860), Shaw (1918), Fisk (1944), Wright (1951) and Kolb et al. (1968). Several unconformities have been identified between Eocene formations in surrounding counties. These unconformities may possibly be an easterly continuation of the single erosion surface identified in our study area. Such unconformities between Eocene formations have been reported by Vestal (1954) in Marshall County, by Turner (1952) in Yalobusha County and by Attaya (1951) in Lafayette County. These unconformities include surficial sands identified as the Kosciusko formation unconformably overlying the Zilpha formation and surficial sands identified as the Meridian formation unconformably overlying the Ackerman (Wilcox) formation. As noted previously, Hilgard (1860) considered these surface materials to be Quaternary in age. We believe that any such age definition is questionable at this time.

3.1.4 Speculation

Several erosional surfaces have been reported in the upper Mississippi River drainage area. As examples, Willman and Frye (1969) reported extensive dissection of a late-Tertiary surface developed on Galena

Dolomite in the Driftless Area of Illinois; Horberg (1950) observed gravels disconformably overlying an erosion surface which developed on Eocene sediments and Frye and Leonard (1952) described a severely eroded late-Tertiary surface in Kansas overlain by gravels at elevations as much as 300 feet above present flood plain level. Thornbury (1965) noted various opinions concerning these midwestern erosion surfaces but concluded that they are time equivalent, resulting from a major mid-Tertiary erosion cycle. He assumed that these surfaces developed contemporaneously with the Harrisburg peneplain in the Appalachians. Gravel deposits of similar lithology, variously identified as Lafayette, Citronelle or Grover, typically overlie such midwestern erosion surfaces.

The similarities between the observed erosion surface in northern Mississippi and those reported in the midwest suggests that these surfaces may be comparable and that all may have formed in response to Tertiary sea-level control. According to Worsley and Davies (1979), sea levels were approximately 600 feet above present from about 45 to 30 million years ago, and then regressed to about 300 feet below present during the next several million years. Gradual sea transgression began prior to 25 million years ago and continued until about 15 million years ago, attaining a maximum elevation of about 250 feet above present sea level. After a relatively short stillstand, the sea levels regressed to about 200 feet below present. This condition persisted into the Pleistocene. Worsley and Davies (1979) described these sea level changes as eustatic. Similar sea level regressions and transgressions have been described by Melhorn and Edgar (1975) with only a slight time scale variation from the preceding and are being used by Exxon as an aid to their oil exploration (Kerr, 1980). Miocene and younger sea level changes have been reported by Hack (1975) and Hsü (1978) and are again in general agreement with the preceding scenario. As discussed by Worsley and Davies (1979), changes in eustatic sea levels would be associated with concurrent climatic changes. Such climatic changes have been reported. Smith (1976) reported two times of major ocean-water cooling, the first from late-Eocene to middle-Oligocene and the second from middle-Miocene to Pleistocene. These two times of cooling were separated by a warming trend. Late-Miocene cooling has also been reported by Loutit and Kennett (1979) and by Imbrie and Imbrie (1979). The latter consider late-Miocene to be the initial phase of Cenozoic glaciation.

Clearly, such eustatic sea level and concurrent climatic changes imply massive and widespread denudation and sediment movement, particularly for sediments temporarily stored near shore during high ocean stands.

We speculate that the erosion surface on the "Zilpha-Winona" material in Panola County formed in response to sea-level controls as described by Worsley and Davies (1979). According to this scenario, the near-surface materials must be post-Eocene and are present as a veneer superjacent to the erosion surface. We have established that one exposure of the "Tallahatta" layered clay (superjacent to gravel deposits) shows magnetic reversal and is thus older than 700,000 years. An early glacial-age origin for these deposits superjacent to the erosion surface is suggested by (a) the large size of several erratics and (b) the paleocurrent direction recorded by foreset bedding angles. A 36- and a 62.5-pound erratic were exposed in cut banks in the study area and a third chert erratic of approximately 20 cubic feet was observed in the bed of Long Creek. The large size and minimum roundness of these erratics suggests ice-rafting. Sand lenses within the gravel deposits are typically cross-bedded and Autin (1978) has shown that these bedding angles have a bimodal distribution, with one mode aligned to the southwest and a second mode aligned to the east-southeast. This latter bedding direction, together with the southeastern cross-bedding angles reported by Vestal (1956), suggests that some of the gravels were deposited from the ancestral Mississippi River system, possibly as tributary-valley backfills.

3.1.5 Conclusions

We have investigated the surficial stratigraphy in Hotophia, Johnson, Goodwin, and Long Creek watersheds, Panola County, northern Mississippi. As previously described by Vestal (1956), the surficial units include Citronelle, Kosciusko, Tallahatta, Zilpha, and possibly Winona formations. We have observed units that are lithologically equivalent to these formations, but the distribution of the "Kosciusko" and "Tallahatta" is [illegible] incongruent with their present stratigraphic position in the generalized section. "Kosciusko" materials occur superjacent to the Citronelle gravels. "Tallahatta" materials occur within the "Citronelle" gravel deposits and superjacent to the "Zilpha-Winona" materials.

The "Zilpha-Winona" materials are subjacent to an erosional surface that it is an aquiclude and controls subsurface hydrology. It underlies the

entire study area and has high relief that is not conformable with present surface relief. We interpret this surface as one of regional significance and speculate that it is continuous over most of northern Mississippi. We additionally speculate that it may be equivalent to the erosional surface widespread in the upper Mississippi Valley. This speculation is based on the premise that post-Eocene sea level changes were the dominant control of late-Tertiary degradation. If this scenario is correct, the surface materials must be post-Eocene in age, deposited as a veneer superjacent to the erosion surface.

We recommend continued subsurface exploration in northern Mississippi to better define the near-surface stratigraphy, particularly the erosion surface. This information would be applicable to several problem areas including:

a. groundwater hydrology,

b. direct (geologic) control of stream or river response, possibly including controls on the Mississippi River,

c. indirect (geologic) control of stream or river response via direct control of the composition of the valley-fill deposits.

3.2 SUBSURFACE INVESTIGATION IN OTHER AREAS OF NORTH MISSISSIPPI

3.2.1 Study Area And Procedures

Approximately 60 holes were logged in areas outside of the intensive study area. Most of these holes are within the Yazoo-Little Tallahatchie (YLT) watershed. Hole locations are shown in Fig. 11. All holes were drilled in present day valleys. Drilling procedures were variable with sample type ranging from undisturbed cores to auger samples. All holes were 60 feet deep except for the three Chiwapa holes where chalk was encountered at 14 to 24 feet.

These logs represent point values within landscapes and, as such, are not sufficient to characterize a landscape or even a valley reach. They were collected for comparison with results from the intensive study area. Sampling sites were located in areas presently mapped as representative of varying geologic conditions (Fig. 12), varying soil resource areas (Fig. 13) and varying physiography (Fig. 14).

3.2.2 Results And Discussion

The typical sequence observed at these sites was, from surface to depth, a fine-textured Holocene flood-plain deposit overlying unconsolidated sands or sands and gravels of variable age. At 37 sites,

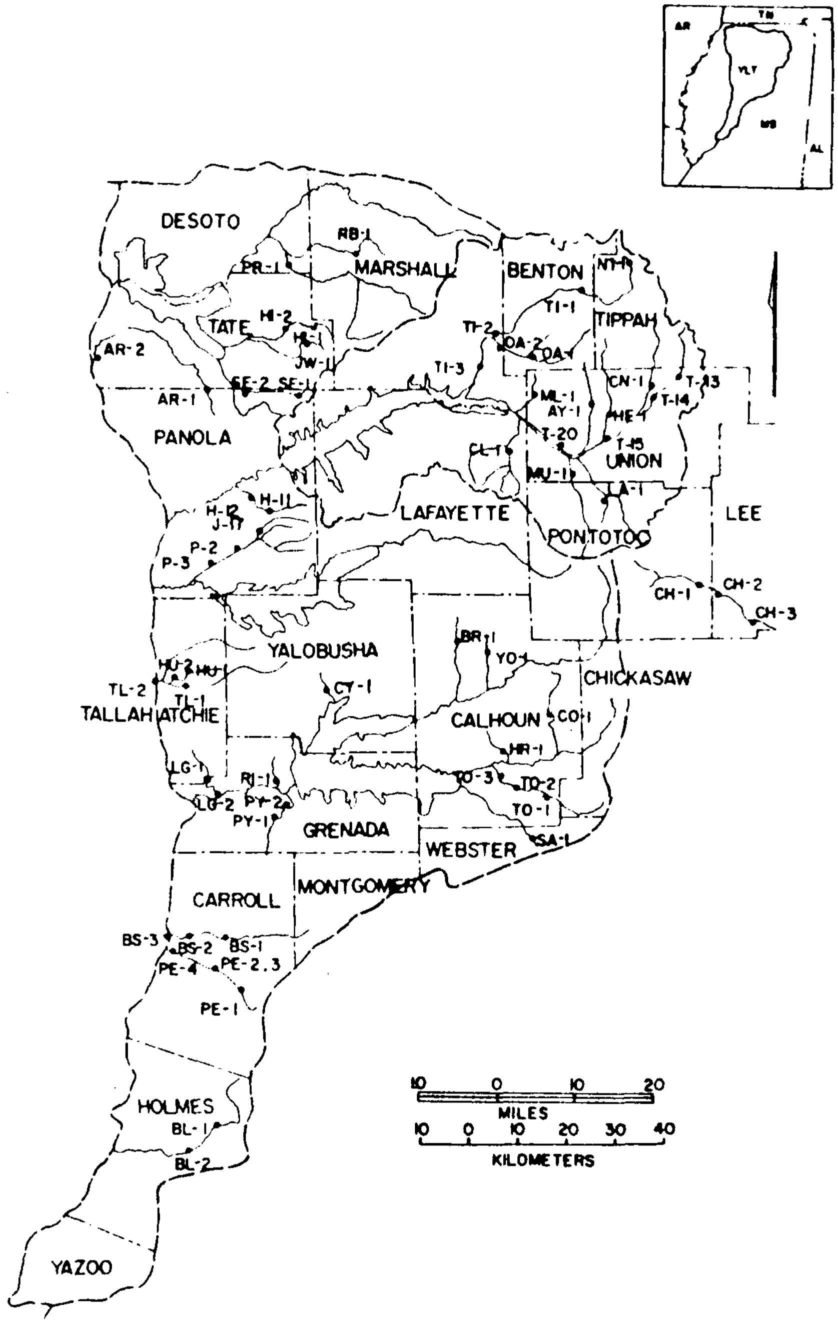

Figure 11 Locations of exploratory holes in YLT watershed. Drilling authorized by the Soil Conservation Service as part of the Inventory and Evaluation of Bank Stabilization Measures (SCS, 1980).

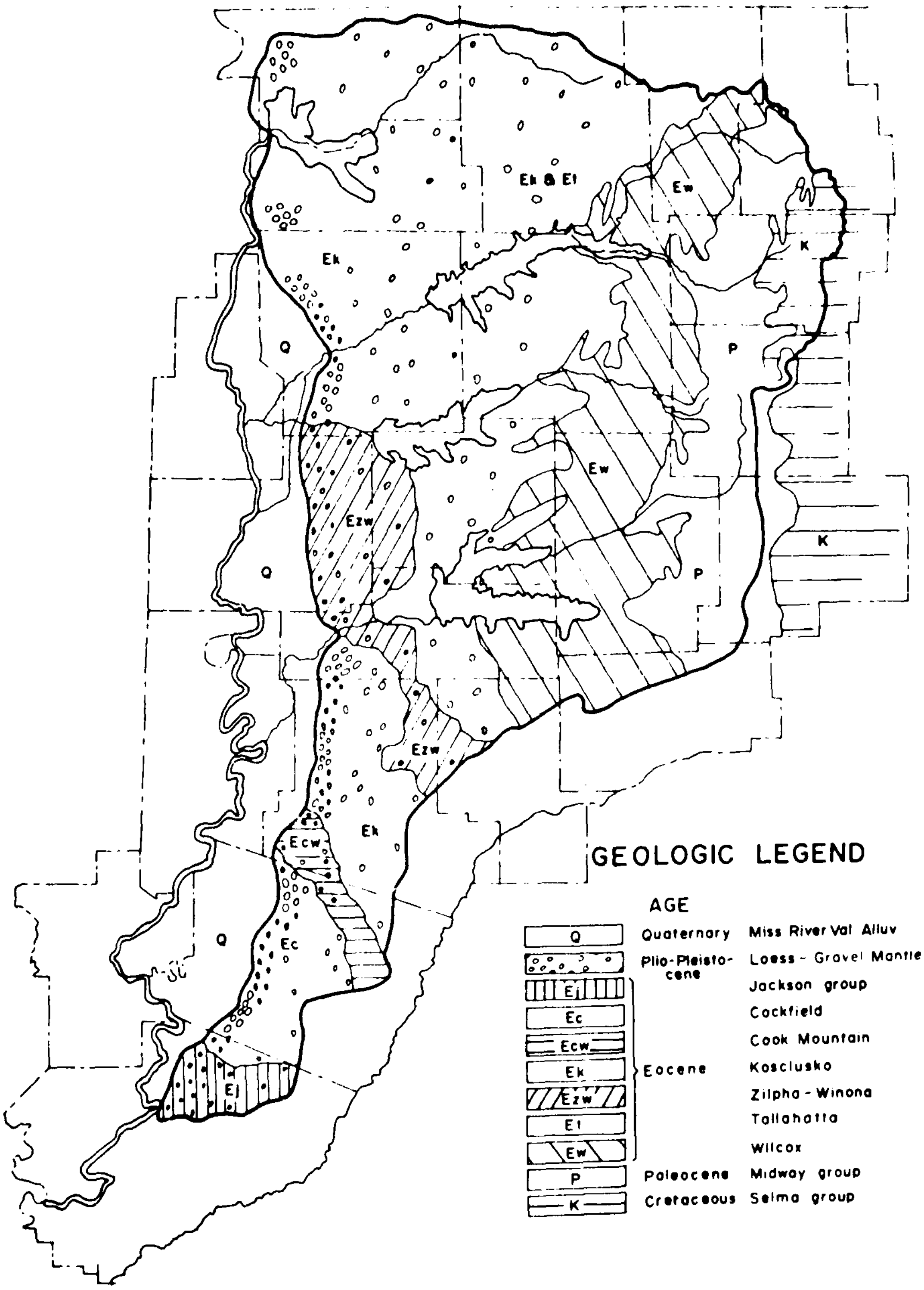

Figure 12 Geology of YLT watershed (after Bicker, 1969).

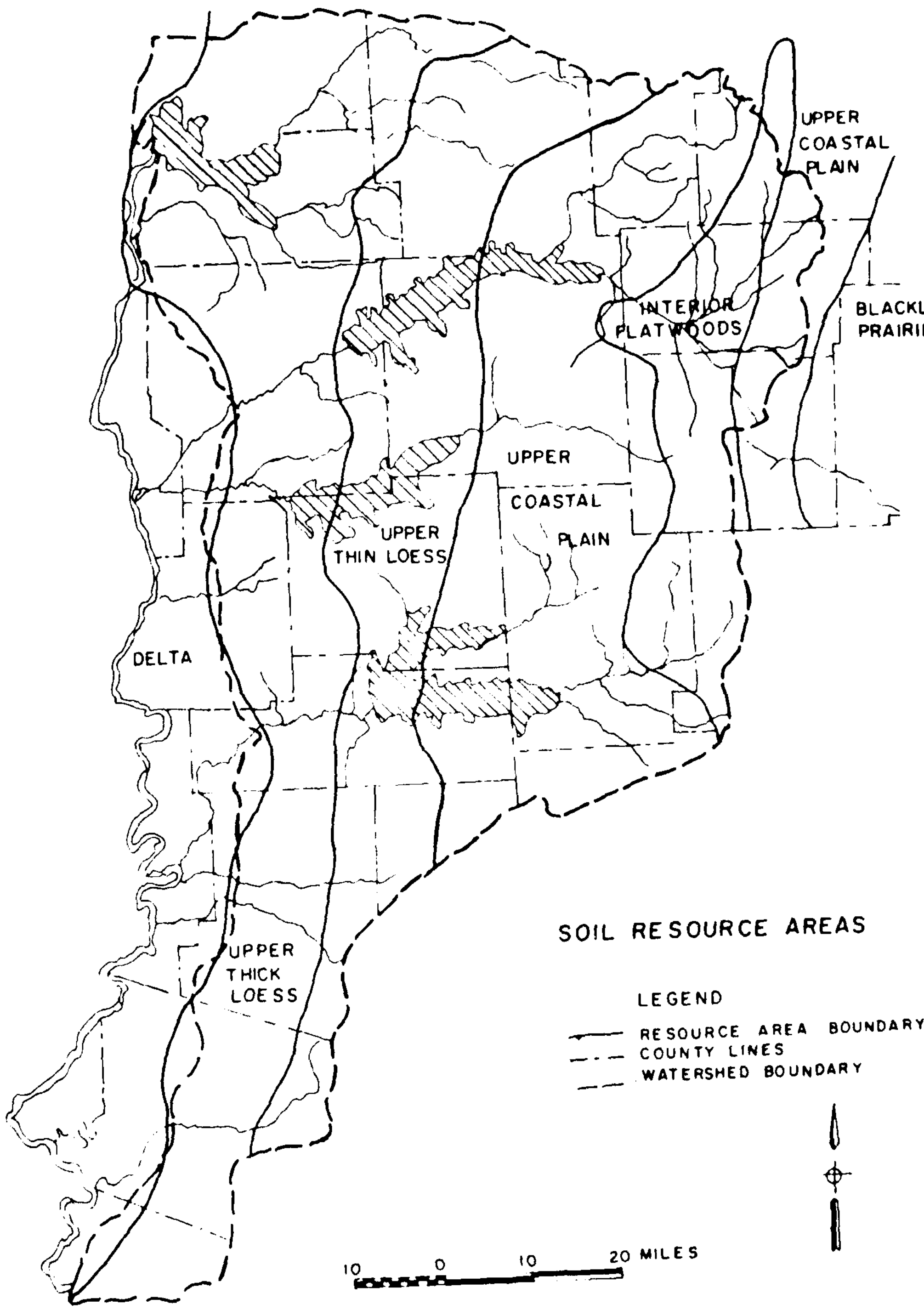

Figure 13 Soil resource areas of the YLT watershed (SCS, 1980).

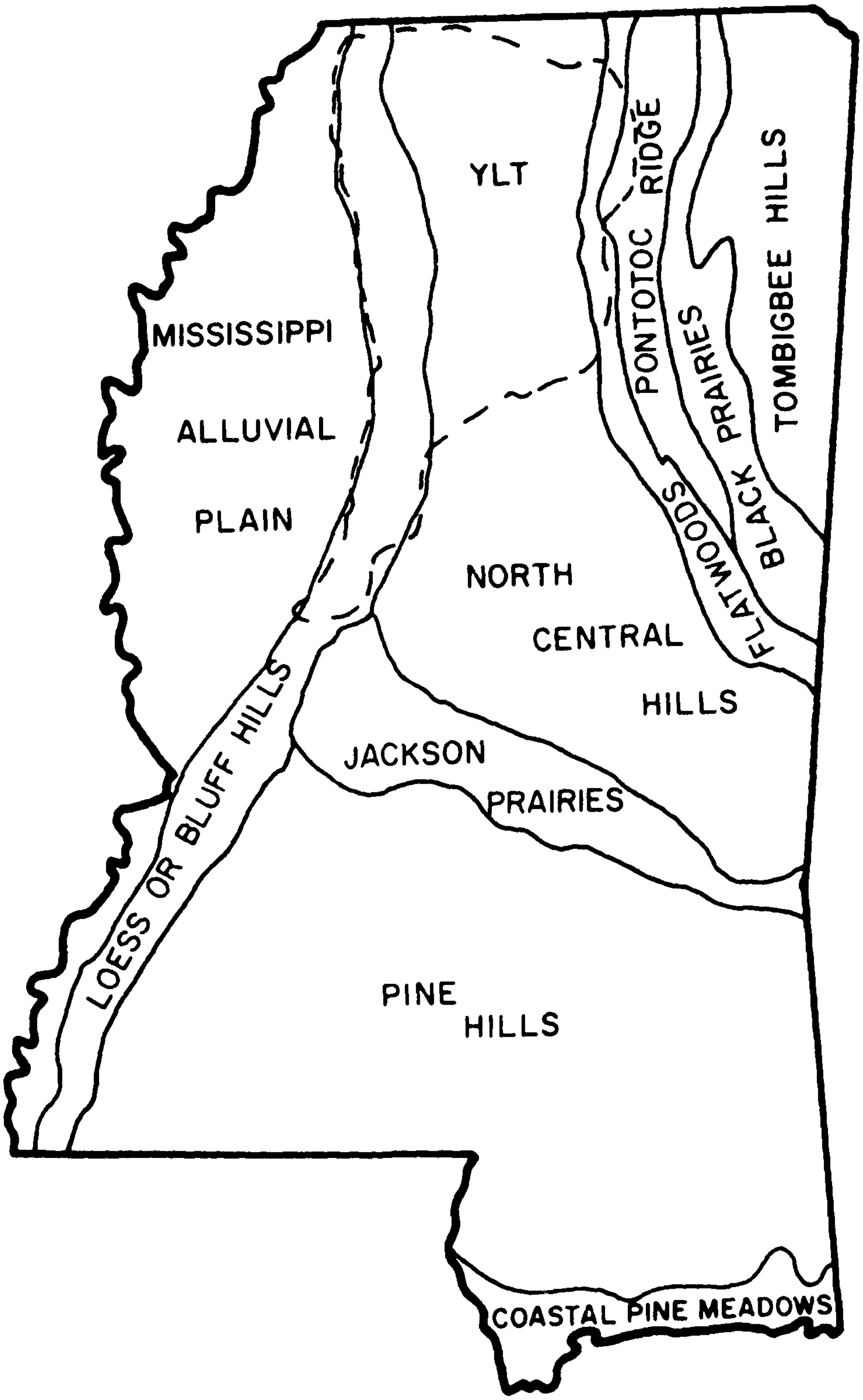

Figure 14 Physiographic Regions of Mississippi (Cross et al., 1974).

the 60-foot depth was sufficient to penetrate through the unconsolidated sands into Eocene or older stratigraphic formations. All of these Eocene or older units were fine-textured, dense materials which we interpret as near-shore marine in origin. Lithologies ranged from that typical of the "Zilpha" (see 3.1.1) to massive fines typical of the Porters Creek clay for the younger materials, to marl or chalk for the basal Paleocene and Cretaceous materials. In several holes, "Zilpha" type materials were interbedded with material having a lithology equivalent with that of Porters Creek clay. Shells and shell fragments were common in samples from basal-Paleocene and Cretaceous source materials. Exceptions to the typical sequence include (a) the five locations (BL-2, HI-1, LA-1, PE-1 and TO-1) with sandy surface deposits and (b) the four locations (CH-3, MU-1, TI-2 and YO-1) which have no coarse-textured material present as discrete lenses or layers below the fine-textured surface material. (Site locations are identified on Fig. 11 with full site names presented in Table 3). All five of the sandy surface materials (the first referenced exception) represent deposits which resulted from man's activities during historic times. This deposit, along with the other valley-fill deposits, are discussed in section 4 of this Appendix. The absence of subsurface sand lenses or layers is undoubtedly due to local conditions at the time of deposition. Subsurface sand lenses or layers were recorded at other sites on both Chiwapa (CH) and Tippah (TI) and at sites in close proximity to both Yoda (YO) and Mud (MU).

Of the 37 holes which penetrated Eocene or older materials, 18 penetrated Eocene materials and 19 penetrated either Paleocene or Cretaceous. All holes positioned in areas older than Eocene penetrated through the unconsolidated sands. Twenty-three of the holes located in Eocene areas did not penetrate through the unconsolidated sands. Most of these holes were either immediately east of the bluff line (the western edge of the study area, Fig. 11) or were in the north-central to northwestern corner of the study area (in Marshall, northern Panola, Benton, DeSoto and Tate Counties). The three other holes which did not penetrate through the unconsolidated sands were CL-1 (Cypress Creek, Lafayette County), CY-1 (Cypress Creek, Yalobusha County) and YO-1 (Yoda Creek, Calhoun County).

Table 3 Location, code (by creek/river) and age of pre-Quaternary surface or near-surface materials (a).

Code	Creek/River	County (s)	Fig. No(s).	Age (b)
AR	Arkabutla	Panola, Tate	11	Eocene
AY	Ayers	Union	11	Paleocene
BL	Black	Holmes	11	Eocene
BR	Brushy	Calhoun	11	Eocene
BS	Big Sand	Carroll	11	Eocene
BU	Burney	Lafayette	16	Eocene
C	Caney	Panola	3	Eocene
CH	Chiwapa	Lee, Pontotoc	11	Cretaceous
CL	Cypress	Lafayette	11	Eocene
CN	Cane	Union	11	Cretaceous
CO	Cook	Calhoun	11	Paleocene
CY	Cypress	Yalobusha	11	Eocene
G	Goodwin	Panola	3	Eocene
H	Hotophia	Panola	3, 11, 16	Eocene
HE	Hell	Union	11	Paleocene
HI	Hickahala	Tate	11	Eocene
HR	Hurricane	Calhoun	11	Paleocene
HU	Hunter	Tallahatchie	11	Eocene
J	Johnson	Panola	3, 11	Eocene
JW	James Wolf	Tate	11	Eocene
L	Long	Panola	3	Eocene
LA	Lappatubby	Pontotoc	11	Paleocene
LG	Long	Grenada	11	Eocene
LI	Lick	Phillips (Arkansas)	16	Paleocene
ML	Mill	Union	11	Paleocene
MU	Mud	Union	11	Paleocene
NT	North Tippah	Tippah	11	Paleocene
OA	Oaklimeter	Benton, Marshall	11	Eocene
P	Peters (c)	Panola	3, 11, 16	Eocene
PE	Pelucia	Carroll	11	Eocene
PR	Pigeon Roost	DeSoto	11	Eocene
PY	Perry	Grenada	11, 16	Eocene
RB	Red Banks	Marshall	11	Eocene
RI	Riverdale	Grenada	11	Eocene
SA	Sabougla	Webster	11	Eocene
SE	Senatobia	Panola	11	Eocene
T	Tallahatchie	Panola, Union	3, 11, 16	{Eocene(Fig.3) {Paleocene(Fig.11,T-15,20 {Cretaceous(Fig.11,T-13,1
TI	Tippah	Benton, Marshall	11	Eocene
TL	Tillatoba	Tallahatchie	11, 16	Eocene
TO	Topashaw	Calhoun	11, 16	Paleocene
YA	Yalobusha	Grenada	16	-
YC	Yocona	Panola	16	-
YO	Yoda	Calhoun	11	Eocene
YZ	Yazoo	(d)	16	-

Table 3 (cont'd)

(a) Materials immediately below loess, gravels or Quaternary alluvium. All locations are in Mississippi except Lick Creek (LI) which is in Arkansas.

(b) Source: Bicker, (1969).

(c) Identified as Long Creek in report by Soil Conservation Service (1980).

(d) Several counties in the Mississippi Delta.

The distributions of the geologic, physiographic and soil resource units are so similar that no inferences are possible concerning individual influences. More significantly, the distribution of holes which penetrated through the unconsolidated sands, in relation to those that did not, is consistent with the previously discussed presence of terrestial deposits disconformably overlying an erosion surface with high relief. We speculate that the principle drainageway in northern Mississippi during this period of paleosurface formation was located between the present bluffline and the intensive study area of Goodwin, Johnson and Long Creeks, Panola County. This is based on the mean sea level elevations of the basal gravels in the study area relative to that along the bluff line (Fig. 15). We further speculate that the present land surface and paleosurface become conformable to the east.

3.2.3 Conclusions

Results of this survey are consistent with those presented in 3.1. No conflicts have been observed in the results from these two studies. The erosion surface is evidently widespread under much of northern Mississippi and should be accurately defined at least for selected areas. We recommend that drilling and resistivity subsurface explorations be conducted across several watersheds (from divide to divide) along the present bluffline. If warranted, these results should then be used to select a few areas for detailed investigation of this paleosurface and this definition should extend between subsurface divides along the bluffline and to the east. This information would complement that recommended in 3.1.5. In general, this information would aid in better defining the near-surface stratigraphy, a potential result having direct utility to mapping the stratigraphy of the Mississippi River Valley. Additionally, definition of relief on the paleo-surface would complement studies of fault activity and the significance of such activity on present-day river behavior.

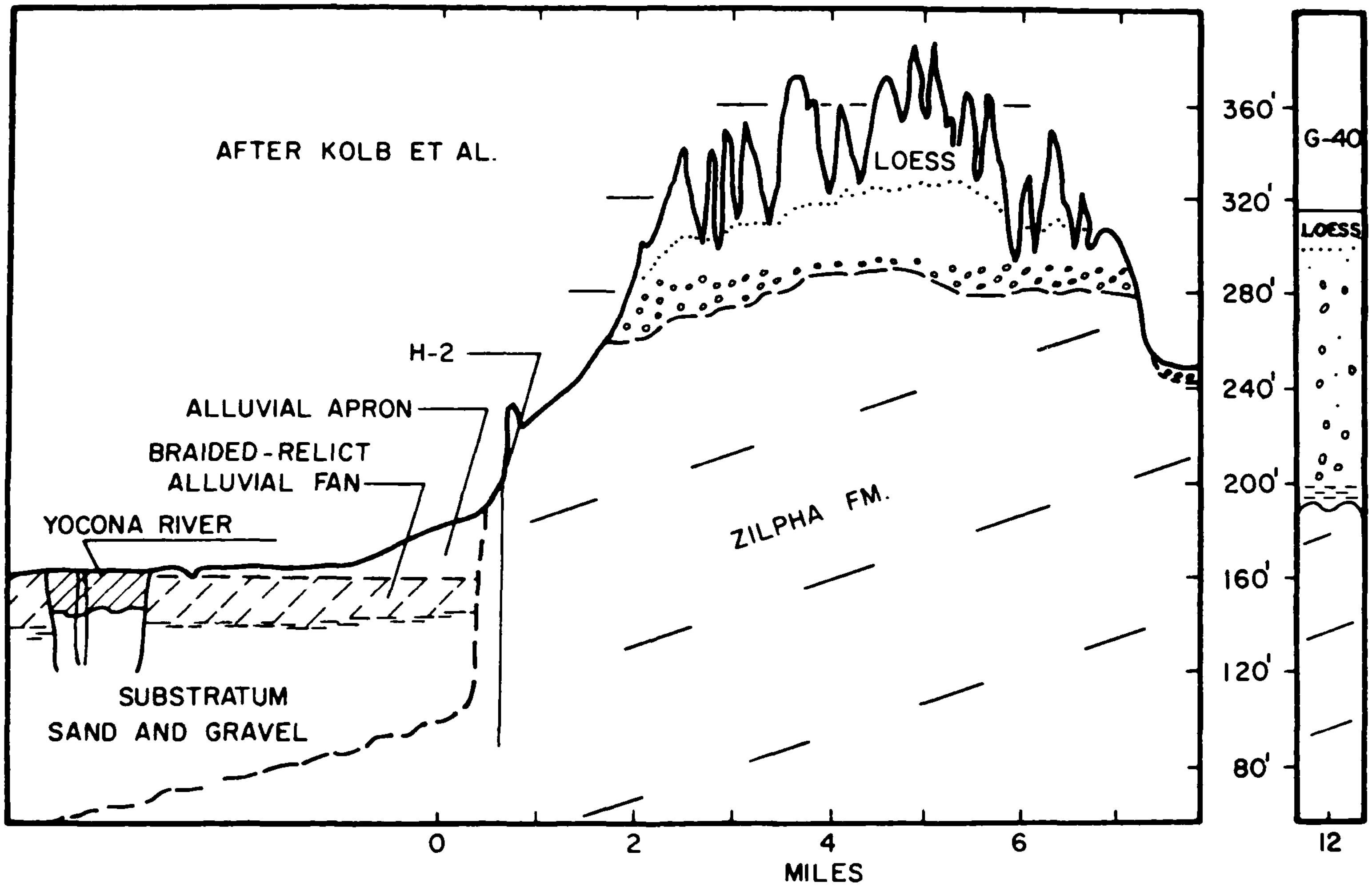

Figure 15 Comparison of basal gravel elevations in feet m.s.l. at Bluff Line (after Kolb et al., 1968, Crowder Quad.) and at hole G-40, about 11.5 miles ENE (see Figs. 3 for location, 7 for profile and 9 for relief of "Zilpha-Winona" surface in intensive study area).

4 LATE-QUATERNARY VALLEY-FILL DEPOSITS

4.1 INTRODUCTION

As an initial phase of a comprehensive study of stream channel instability, we visually inspected many streams east of the bluff line. Bed and bank materials were not uniform for any individual stream channel. We observed, however, that most materials could be grouped into one of several units. Each of these individual units had a consistent appearance throughout the study area and each possessed distinctive properties facilitating differentiation between units. Additionally, each unit occupied a consistent relative position in all watersheds. These observations indicated that the alluvial deposits, presently undifferentiated, may include several stratigraphic units. This section presents the results of our study of these alluvial deposits including (a) the distinguishing properties of each unit and (b) the chronology of the units.

4.2 VALLEY-FILL DEPOSITS

Seven identifiable valley-fill units regularly crop out in channels of the study area. Two additional units have been observed along one reach on Johnson Creek. Most drill samples fit this unit classification; only 18 such samples are presently undifferentiated. The units contain abundant wood or other organic detritus. Wood identifications and ^{14}C ages are listed by sample locations in Table 4, and sample locations are shown in Figs. 11 (for drill samples) and 16 (for outcrop samples). A frequency histogram for outcrop samples of ages less than 13,000 ^{14}C years Before Present (yr BP) is presented in Figs. 17a and 18a. The outcrop samples collected over long channel reaches are thought to be more representative of age frequencies than are the drill samples which represent only one point in the landscape. The comparable frequency histogram for all samples is presented in Fig. 18b. All ages were calculated using the Libby half-life of 5568 years. No correction has been made for variation in atmospheric ^{14}C concentration. Seven regularly occurring process units have been identified. These units, from oldest to youngest, are (a) consolidated sandstone, (b) bog-type deposit, (c) channel lag deposit, (d) massive silt, (e) channel fill, (f) meander-belt alluvium and (g) postsettlement alluvium. These units are discussed in sections 4.2.1 through 4.2.4. The gray silt and organic sandy silt units which were observed only on Johnson

Table 4. Age and wood identification of carbon samples by type of deposit and location (a).

Type of Deposit / Sample Number Sed Lab/Teledyne	Drill Hole (b)	Depth meters	Wood Identification	^{14}C Age (Yr BP±s)
		Stream, County		
		Amite, Saint Helena(c)		
Undifferentiated				
C-98/I-11,062		3.4	*Pinus* sp.	600±75
		Amite, Livingston(c)		
Undifferentiated				
C-99/I-11,063		4.0	*Taxodium* sp.	2,060±80
C-100/I-11,064		0.9	*Liquidambar styraciflua*	<185
C-101/I-11,065		1.8	*Platanus occidentalis*	235±75
		Black, Holmes		
Meander-belt alluvium				
C-104/I-11,177	BL-2(Fig.11)	5.9-6.0	*Ulmus* sp.	2,840±90
		Brushy, Calhoun		
Meander-belt alluvium				
C-125/I-11,276	BR-1(Fig.11)	2.9	*Taxodium* sp.	235±75
C-126/I-11,277	BR-1(Fig.11)	4.3		765±80
Channel fill				
C-127/I-11,278	BR-1(Fig.11)	5.2-5.5		5,270±110
		Burney, Lafayette		
Postsettlement alluvium				
C-38/I-10,449		2.7	*Quercus* sp.	<190
Meander-belt alluvium				
C-[illegible]/I-10,450		3.0	*Quercus* sp.	395±75
C-[illegible]/I-10,214		3.0	*Castanea dentata*	380±80
		Coldwater tributary, DeSoto(d)		
Undifferentiated				
C-[illegible]3/I-11,630	EG3-7	15.7		>40,000
C-205/I-11,635	DO-16-1C	10.7	*Populus* sp.	3,570±95

Table 4 (Cont'd)

		Goodwin, Panola		
Meander-belt alluvium				
C-44/I-10,452		1.8	*Populus* sp.	250±75
C-45/I-10,215		2.7	*Liquidambar styraciflua*	330±80
C-80/I-11,042		2.4	*Quercus* sp.	195±75
C-81/I-11,043		4.6	*Fraxinus* sp.	1,895±80
C-82/I-11,044		5.2	*Carya* sp.	195±75
C-83/I-11,045		4.9	*Rhamnus caroliniana*	205±75
C-84		4.9	*Liriodendron tulipifera*	(e)
C-85		4.9	*Fraxinus* sp.	(e)
C-86		4.9	*Quercus* sp.	(e)
C-87		4.9	*Quercus* sp.	(e)
C-89/I-11,047		1.8	*Salix* sp.	195±75
C-91/I-11,048		3.0	*Liquidambar styraciflua*	310±75
Channel fill				
C-16/I-10,395		5.7	*Liriodendron tulipifera*	4,545±95
C-88/I-11,046		4.3	*Quercus* sp.	5,830±115
Channel lag				
C-15/I-10,200		5.8	*Ulmus rubra*	9,460±140
Bog-type				
C-46/I-10,576		3.7	*Juglans* sp.	9,750±140
Undifferentiated				
C-59/I-10,692	G-22(Fig.3)(f)	20.3		>40,000
C-61/I-10,693	G-22(Fig.3)(f)	38.1		>40,000
		Hickahala, Tate		
Channel fill				
C-133/I-11,538	HI-2(Fig.11)	6.7-7.3		5,830±115
		Hotophia, Panola		
Postsettlement alluvium				
C-1/I-9913		1.8	*Liquidambar styraciflua*	<185
Meander-belt alluvium				
C-2/I-10,385		3.7	*Prunus* sp.	1,450±85
C-3/I-10,386		4.6		1,820±85
C-191/I-11,575	H-13(Fig.3)	4.5-4.6	*Quercus* sp.	1,565±80
Channel fill				
C-4/I-9914		4.6	*Taxodium distichum*	5,600±110
C-102/I-11,251	H-7(Fig.3)	5.8		7,100±240
C-103/I-11,252	H-7(Fig.3)	4.6		6,270±200

Table 4 (Cont'd)

Channel lag				
C-50/I-10,580	H-6(Fig.3)	8.5		12,050±180
C-97/I-11,061	H-9(Fig.3)	4.7	Quercus sp.	10,850±150
C-131/I-11,284	H-11(Fig.3)	5.0	Fagus grandiflora	10,170±150
C-194/I-11,608		4.7-5.0	Quercus sp.	13,130±170
Bog-type				
C-49/I-10,579		6.4	Ulmus sp.	11,880±170
C-52/I-10,615		6.4	Acer sp.	11,330±170
C-53/I-10,616		6.4	Acer sp.	11,660±170
Undifferentiated				
C-51/I-10,581	H-6(Fig.3)	12.3-13.1		>40,000
		Hunter, Tallahatchie		
Meander-belt alluvium				
C-115/I-11,175	HU-1(Fig.11)	3.7-4.6		395±95
		Johnson, Panola		
Postsettlement alluvium				
C-65/I-10,939		3.2	Quercus sp.	>190
C-94/I-11,058		2.1	Liquidambar styraciflua	>185
Meander-belt alluvium				
C-47/I-10,577		2.0	Castanea dentata	575±75
C-48/I-10,578		3.8	Sassafras albidum	955±80
C-63/I-10,695		4.0	Acer sp.	470±80
C-66/I-10,940		4.0		2,980±85
C-70/I-10,953		4.3	Cercis canadensis	225±75
C-74/I-10,957		4.0	Carya sp.	250±75
C-75/I-10,964		4.0	Quercus sp.	325±75
C-95/I-11,059		6.4	Ulmus americana	1,655±80
C-96/I-11,060		3.0	Quercus sp.	1,110±85
C-182/I-11,557		4.0	Ulmus sp.	360±75
Channel fill				
C-108/I-11,181		5.8	Quercus sp.	6,000±115
C-109		5.8	Hardwood	(g)
C-110		5.8	Ulmus	(g)
C-111		5.8	Ulmus	(g)
C-112		5.8	Castanea dentata	(g)
C-113		5.8	Platanus sp.	(g)
Bog-type				
C-68/I-10,942		3.7	Betula sp.	11,070±160
C-69/I-10,943		4.6	Quercus sp.	10,110±150
C-71/I-10,954		4.3	Ulmus rubra	9,485±160
C-72/I-10,955		4.1	Quercus sp.	8,550±140
C-73/I-10,956		4.0	Quercus sp.	8,830±145
C-76/I-10,965		4.1	Fagus grandifolia	8,740±145

Table 4 (Cont'd)

Channel lag				
C-64/I-10,696		4.0	Platanus occidentalis	9,640±155
C-67/I-10,941		3.4	Hardwood	10,030±150
C-92/I-11,049		4.0	Quercus sp.	9,860±140
C-93/I-11,057		4.0	Fagus grandifolia	9,920±140
C-178/I-11,556		4.7	Quercus sp.	10,280±150
C-179		4.7	Hardwood	(h)
C-180		4.7	Fagus grandifolia	(h)
C-181		4.7	Fagus grandifolia	(h)
C-188/I-11,573		4.7	Quercus sp.	10,230±150
Gray silt				
C-183/I-11,558		5.0	Liriodendron tulipifera	9,490±150
C-184/I-11,572		5.0	Salix or Populus sp.	9,330±150
C-185		5.0	Liriodendron tulipifera	(i)
C-186		5.0	Fagus grandifolia	(i)
C-187		5.0	Fagus grandifolia	(i)
Organic sandy silt				
C-196/I-11,609		5.2		21,250±450
C-197/I-11,610(j)		5.2		13,960±370
		Jones, Panola		
Undifferentiated				
C-189/I-11,574	T-2(Fig.3)	10.4-10.5	Quercus sp.	>40,000
C-190/I-11,607	T-2(Fig.3)	10.5-10.7	Quercus sp.	>40,000
		Lick, Phillips		
Bog-type				
C-9/I-10,197		5.5	Fagus grandifolia	9,510±140
		Long, Panola		
Postsettlement alluvium				
C-23/I-10,412		3.7	Quercus sp.	<195
Meander-belt alluvium				
C-20/I-10,398		5.2	Juglans nigra	2,365±85
C-21/I-10,211		6.4	Liquidambar styraciflua	190±80
C-56/I-10,618		3.0	Ulmus americana	210±75
C-57/I-10,619		5.0	Castanea dentata	405±75
C-58/I-10,691		5.0	Cercis canadensis	455±80
Channel fill				
C-124/I-11,275		6.0		4,050±130
Consolidated sandstone				
C-55/I-10,617		6.7	Conifer(k)	>40,000

Table 4 (Cont'd)

		Lappatubby, Pontotoc		
Channel fill				
C-168/I-11,554	LA-1(Fig.11)	5.5	*Quercus* sp.	4,790±100
C-169/I-11,555	LA-1(Fig.11)	4.0		4,630±95
		Mill, Union		
Channel lag				
C-153/I-11,552	ML-1(Fig.11)	4.6	Hardwood	9,670±150
C-158/I-11,553	ML-1(Fig.11)	6.1-7.0		9,490±140
		Oaklimeter, Benton		
Channel fill				
C-201/I-11,628		4.6	*Quercus* sp.	2,850±90
		Oil, Panola		
Channel fill				
C-192/I-11,576	T-3(Fig.3)	4.4-4.6		3,500±95
		Pelucia, Carroll		
Meander-belt alluvium				
C-105/I-11,178	PE-2(Fig.11)	2.9-3.0	*Quercus* sp.	2,150±80
		Perry, Grenada		
Meander-belt alluvium				
C-18/I-10,210		4.7	*Catalpa* sp.	1,260±80
C-19/I-10,397		2.7	*Quercus* sp.	270±80
Channel fill				
C-17/I-10,396		4.6	*Sassafras albidum*	4,830±100
		Potacocowa, Carroll(1)		
Undifferentiated				
C-198/I-11,611		6.1	*Ulmus* sp.	5,950±110
		Riverdale, Grenada		
Undifferentiated				
C-[illegible]7/I-11,180	RI-1(Fig.11)	8.8-9.1		>40,000
		Sabougla, Webster		
Meander-belt alluvium				
C-121/I-11,254	SA-1(Fig.11)	3.7	*Quercus* sp.	2,180±85
C-122/I-11,255	SA-1(Fig.11)	4.3-5.2	*Quercus* sp.	2,520±85
C-123/I-11,274	SA-1(Fig.11)	6.1-6.7		2,710±85

Table 4 (Cont'd)

		Senatobia, Panola		
Meander-belt alluvium				
C-132/I-11,384	SE-2(Fig.11)	4.3	Quercus sp.	355±75
		Strayhorn, Tate(1)		
Undifferentiated				
C-199/I-11,626		6.1	Hardwood	6,330±110
		Tallahatchie, Union		
Meander-belt alluvium				
C-148/I-11,542	T-14(Fig.11)	4.6-5.2	Diospyros virginiana	3,050±90
Bog-type				
C-145/I-11,541	T-13(Fig.11)	4.9-5.2		10,310±150
		Tillatoba, Tallahatchie		
Meander-belt alluvium				
C-6/I-9,915		2.0		990±80
C-5		2.1	Quercus sp.	(m)
C-7		1.8	Quercus sp.	(m)
C-41/I-10,451		4.3	Liriodendron tulipifera	305±75
C-42		4.3	Acer sp.	(n)
C-43		4.3	Platanus occidentalis	(n)
C-27/I-10,415	(o)	5.2	Quercus sp.	1,315±80
C-28/I-10,416	(o)	7.0	Platanus occidentalis	2,405±90
Channel fill				
C-62/I-10,694		4.9	Fraxinus sp.	6,120±115
C-77/I-10,966		5.5	Fraxinus sp.	5,380±105
C-78		5.5	Fraxinus sp.	(p)
C-79		5.5	Fraxinus sp.	(p)
C-116/I-11,253	TL-1(Fig.11)	7.0		4,140±220
C-119/I-11,176	TL-2(Fig.11)	6.1-6.4	Fraxinus sp.	6,840±115
C-26/I-10,212	(o)	5.8	Celtis occidentalis	4,050±105
Channel lag				
C-24/I-10,413	(o)	8.8	Ulmus americana	10,550±150
C-25/I-10,414	(o)	8.8	Betula nigra	10,280±150
C-29/I-10,447	(o)	7.0	Fagus grandifolia	9,840±150
C-31/I-10,213	(o)	10.7	Platanus occidentalis	10,200±150
C-32	(o)	(q)	Ulmus rubra	(q)
C-33	(o)	(q)	Platanus occidentalis	(q)
C-34	(o)	(q)	Quercus sp.	(q)
C-35	(o)	(q)	Quercus sp.	(q)
C-36	(o)	(q)	Betula nigra	(q)
C-37	(o)	(q)	nuts of Juglans & Carya sp.	(q)

Table 4 (Cont'd)

Bog-type				
C-30/I-10,448	(o)	10.8		10,760±150
		Tippah, Benton		
Meander-belt alluvium				
C-200/I-11,627		3.0	Hardwood	435±75
		Tippah, Marshall		
Meander-belt alluvium				
C-138/I-11,539	TI-2(Fig.11)	5.5		620±75
Undifferentiated				
C-137/I-11,495(j)	TI-3(Fig.11)	13.4-13.7		17,050±350
C-139/I-11,416	TI-3(Fig.11)	15.7-16.3		>40,000
		Tombigbee, Monroe(r)		
Undifferentiated				
C-202/I-11,629		6.1	*Quercus* sp.	33,200±1,600
		Topashaw, Calhoun		
Bog-type				
C-8/I-9,917		5.6	*Quercus* sp.	10,080±145
C-10/I-10,387		5.6	*Quercus* sp.	10,730±150
Channel lag				
C-12/I-10,199		6.5	*Quercus* sp.	9,410±140
C-14/I-10,389		6.5	*Quercus* sp.	9,460±140
Consolidated sandstone				
C-11/I-10,198		7.2	*Platanus occidentalis*	>40,000
C-13/I-10,388		7.3	Hardwood	>40,000
		Yoda, Calhoun		
Undifferentiated				
C-130/I-11,283	YO-1(Fig.11)	16.2-16.8		34,900±2,100

(a) All streams are in Mississippi except Lick Creek which is in Arkansas and the Amite River which is in Louisiana. Drill hole samples were classified using the same lithologic criteria as described for unit outcrops. Weathering properties are less significant for deeper samples.

(b) No entry signifies outcrop sample.

(c) Samples supplied by W. Autin, Louisiana Geological Survey.

Table 4 (Cont'd)

(d) Samples supplied by and hole identification that of Mississippi Geological Survey.

(e) Samples from same deposit as C-80 through C-83.

(f) Between G-30 and G-36 (Fig.3).

(g) Samples from same deposit as C-108.

(h) Samples from same deposit as C-178.

(i) Samples from same deposit as C-183,184.

(j) Small sample - not treated to completely remove all humic acids.

(k) Iron-replaced wood.

(l) Samples supplied by S. C. Happ.

(m) Samples from same deposit as C-6.

(n) Samples from same deposit as C-41.

(o) Samples from excavation for SCS drop structure.

(p) Samples from same deposit as C-77.

(q) Miscellaneous samples from lower elevation at excavation site. This area was disturbed, but all samples are thought to be from channel lag deposits.

(r) Sample supplied by K. P. McLaughlin, Geology Department, University of Mississippi.

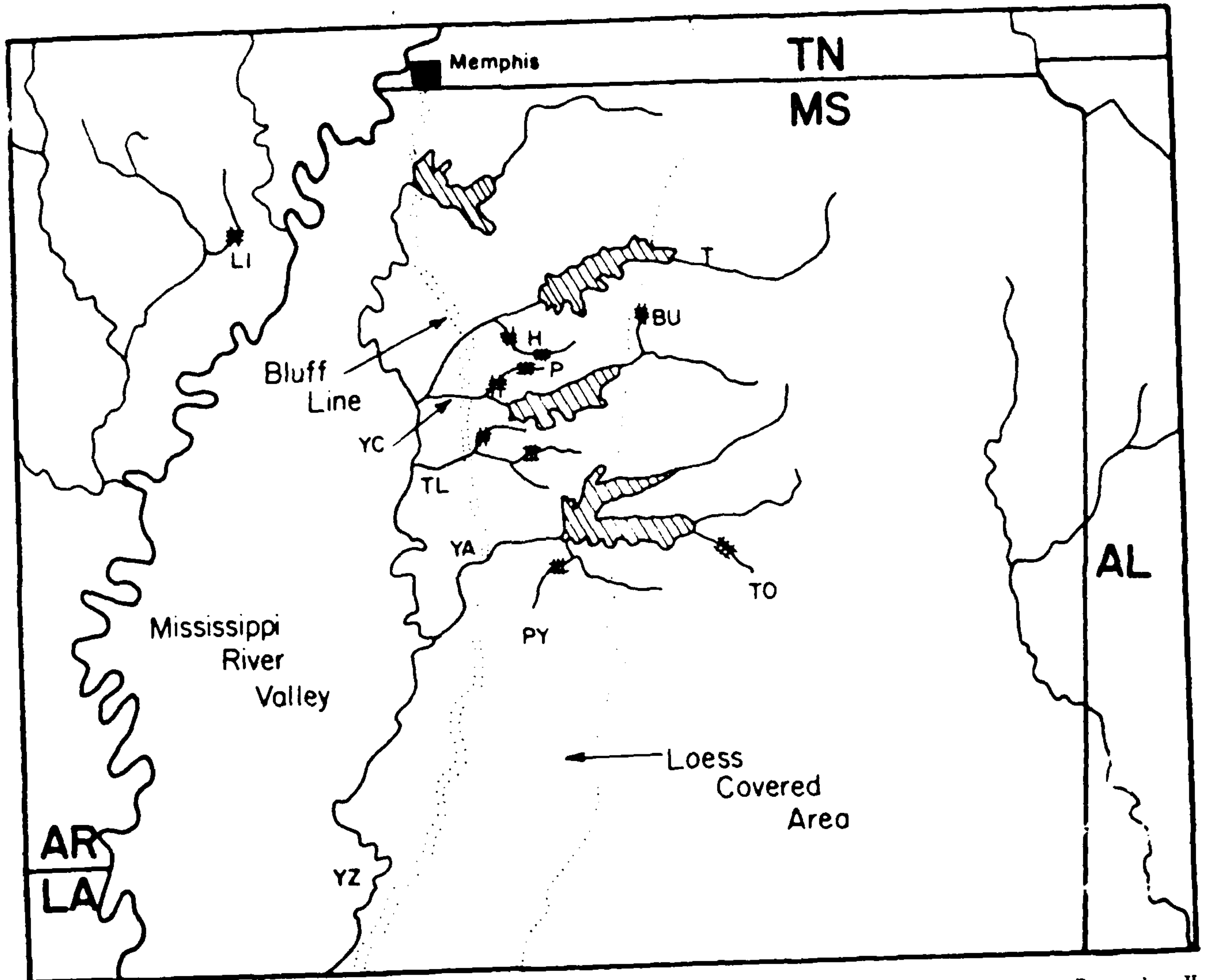

Figure 16 Locations of ^{14}C outcrop samples in north-central Mississippi: BU is Burney Branch; H is Hotophia Creek; PY is Perry Creek; P is Peters Creek including Long, Goodwin and Johnson Creek tributaries; T is Tallahatchie River; TL is Tillatoba Creek; TO is Topashaw Creek; YA is Yalobusha River; YC is Yocona River and YZ is Yazoo River. The sample from Lick Creek, Arkansas (identified as LI) is outside of the main area of study. General sample locations are identified by hatch lines.

Creek are discussed in sections 4.2.1 and 4.2.3.1. The undifferentiated samples will not be discussed in detail. Specific samples from this group will be referenced where pertinent to the discussion. For the samples which will not be further discussed, seven are drill samples, all of which had ages >40,000 yr BP, and eight samples were collected by associates in watersheds not included in this study. Profile descriptions were not available for these samples. These samples came from the Amite River, Louisiana and the Coldwater, Potacocowa and Strayhorne Rivers of Mississippi. They were dated for comparison with other samples. For these samples, one was >40,000 yr BP, three had ages equivalent to that of meander-belt alluvium, three had ages equivalent to that of channel-fill materials and one was equivalent in age to postsettlement alluvium.

4.2.1 Consolidated Sandstone

Consolidated sandstones are present in many watersheds. These sandstones are usually cross-bedded and frequently contain small amounts of gravel. At three locations the sandstone contained wood all of which was older than 40,000 ^{14}C yr BP (samples I-10,198 and I-10,388, Topashaw Creek and I-10,617, Long Creek, Panola County). Many of these exposures are enriched with iron and frequently contain iron-replaced wood. Four samples of this iron-replaced wood have been identified as a conifer[2/] but the lack of cellular detail prevented further identification. At one location, the carbonized wood (sample I-10,617) was recovered from the center of an outcrop of unusually high iron content. Paleomagnetic analysis was attempted at this and nearby exposures, and the direction of magnetization was found to be scattered about the present normal field direction.[2/] Although the paleomagnetic data should be considered preliminary, they do indicate that the time of iron enrichment was materially younger than the wood age.

Outcrops of the consolidated sandstone are usually limited in size, rarely exceeding several tens of meters in horizontal distances. They are truncated and are typically disconformably overlain by bog-type and channel lag deposits with a maximum age of 12,050±180 yr BP (sample I-10,580,

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2/ Fossil wood identification was performed by S. Manchester, Indiana University. Paleomagnetic analyses were performed by S. Bressler, U.S. Geol. Surv., Flagstaff, AZ.

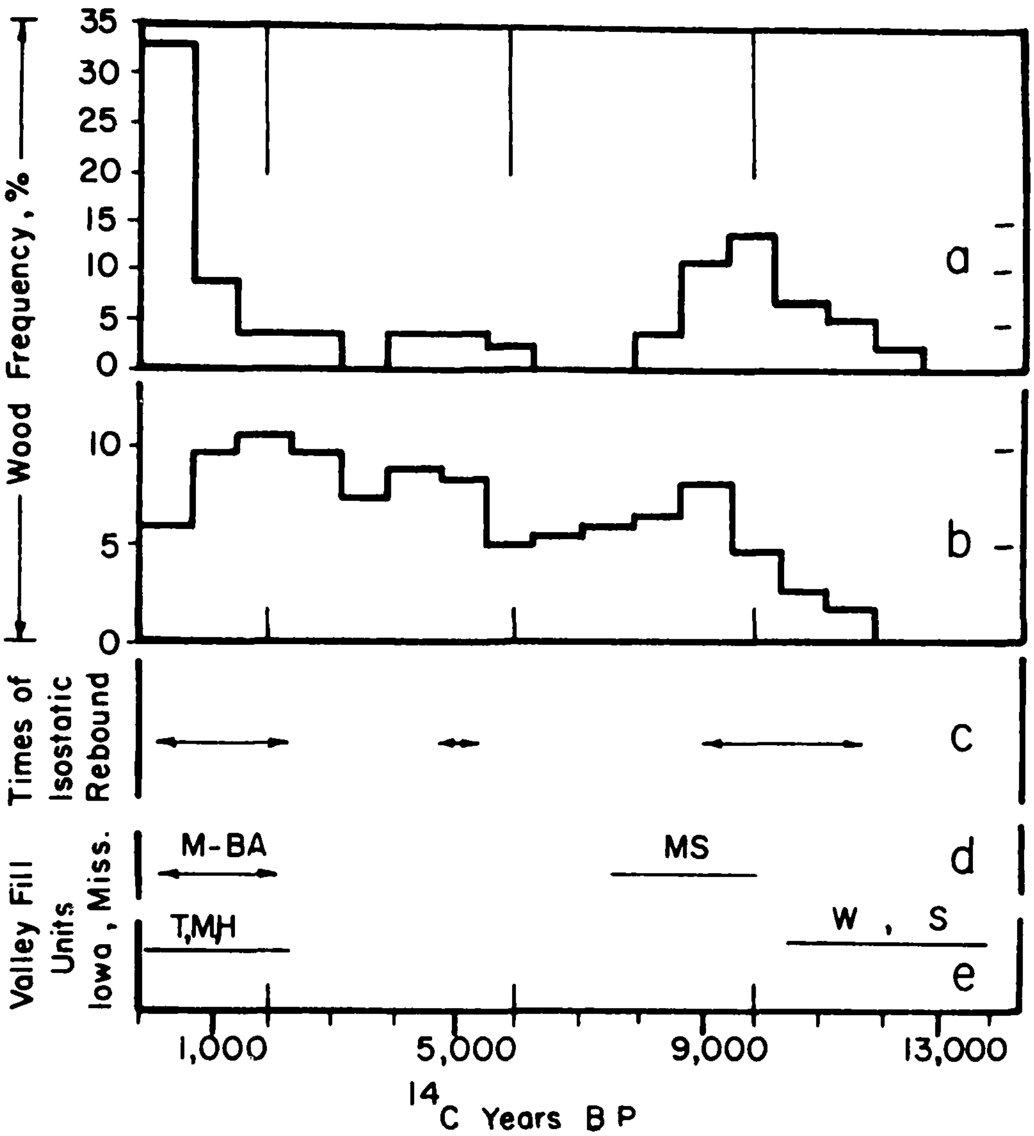

Figure 17 Chronology of valley-fill deposits. (a) Frequency histogram of ^{14}C dates for outcrop samples from north-central Mississippi (source: this paper). (b) Frequency histogram for 815 ^{14}C dates selected from the journal Radiocarbon [source: Wendland and Bryson (1974)]. (c) Times of paleoclimate-controlled isostatic rebound in the Great Lakes area [source: Flint (1957)]. (d) Paleosol ages in north-central Mississippi; M-BA = meander-belt alluvium, MS = massive silt (source: this paper). (e) Valley-fill ages in Iowa; T = Turton, M = Mullenix, H = Hatcher, W = Watkins, S = Soetmelk [source: Daniels and Jordan (1966) and Ruhe (1969)].

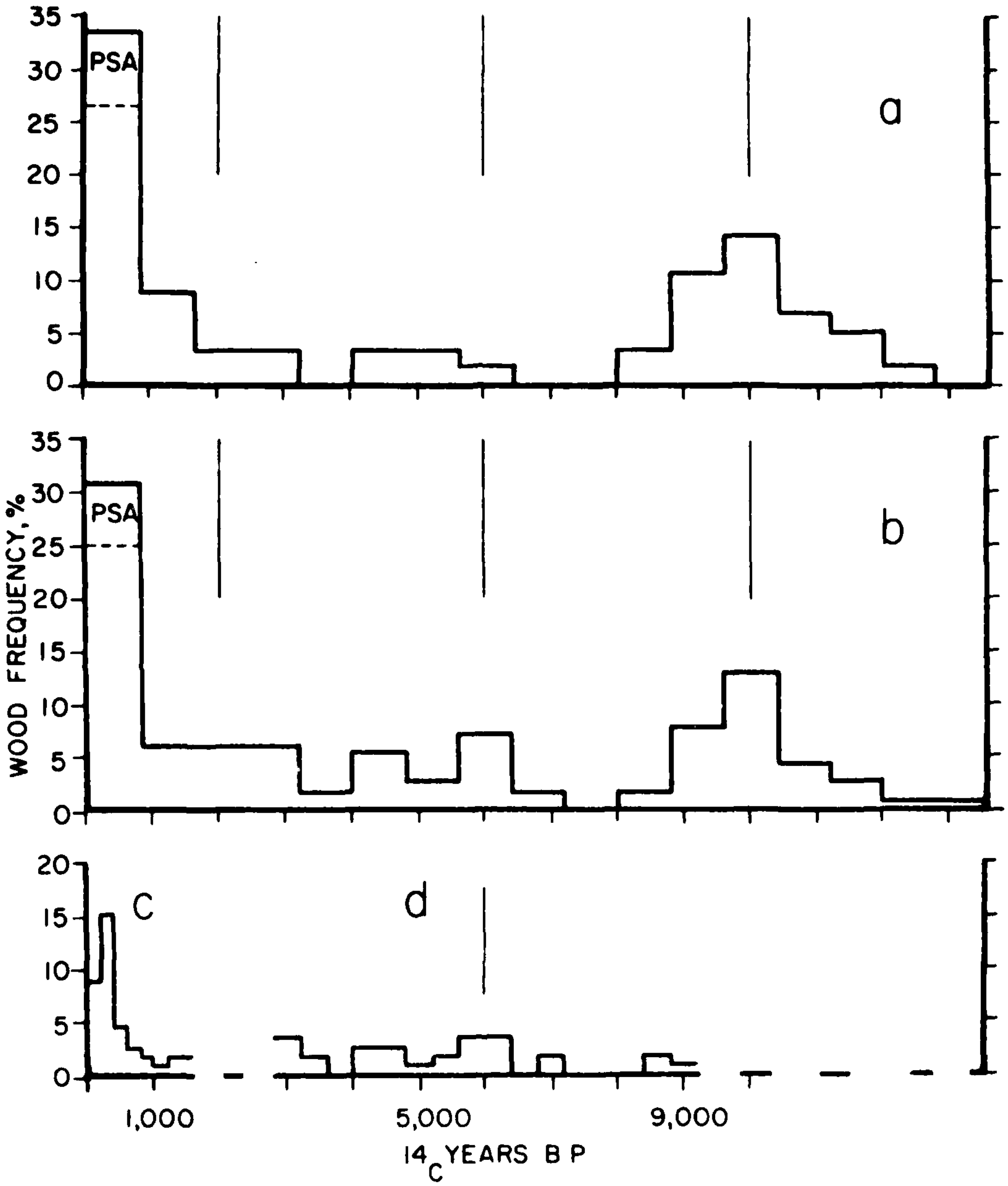

Figure 18. Frequency histograms of ^{14}C dates. (a) Outcrop samples in 800-yr classes. (b) All samples in 800-yr classes. (c) Samples younger than 1600 yr BP in 200-yr classes. (d) Samples comprising the (about) 5000 yr BP mode in 400-yr classes.

Hotophia Creek). This maximum age of the overlying deposits is comparable with the 12,740±300 to 12,600±275 BP ages reported by Delcourt and Delcourt (1977) for wood samples from the base of a fluviatile terrace in southeastern Louisiana. They reported both Picea glauca (white spruce) and Larix laricina (tamarack) fragments in this deposit. A slightly older maximum age, 14,650±500 BP has been reported for a fluvial deposit along the Tombigbee Waterway (Curren et al., 1976), southeast of our study area. Delcourt et al. (1980), however, have reported ages ranging from 17,200 to 22,300 yr BP for deposits within 2 to 3 m of the present surface of Nonconnah Creek valley, immediately south of Memphis, Tennessee. Additionally, the arboreal pollen assemblage of these deposits was dominated by Picea with low concentrations of Abies (fir) and Larix. They reported that macrofossils of Picea glauca were abundant. Mesic species identified in this study are comparable with those in bog-type and channel lag deposits in our study area (Table 5). We have not found any outcrops containing wood of boreal species. Of the 129 samples dated thus far, only two had ages comparable with those reported by Delcourt et al. (1980). An undifferentiated sample, I-11,495 (hole TI-3, Tippah River, Marshall County) was dated at 17,050±350 yr BP and an outcrop sample, I-11,609 (organic sandy silt, upper Johnson Creek, Panola County), was dated at 21,250±450 yr BP. Sample I-11,610 was from the same organic sandy silt deposit on Johnson Creek but was too small for proper pretreatment; this age must be considered questionable. The undifferentiated sample from Tippah River was also too small for proper pretreatment. It occurred as a lense between tight clay layers at a depth of 13.4 to 13.7 m, however, and was less subject to contamination. This age is considered to be relatively accurate. Both of these samples, I-11,495 and I-11,609, occurred below channel lag deposits and neither occurred near the present bluff line.

The paucity of organics with ages comparable with those reported by Delcourt et al. (1980), the absence of fine-textured deposits resembling buried flood-plain deposits (from the drilling program), the absence of boreal species in our samples, the excessive depth of several of the 10,000 yr BP deposits (for examples I-10,448 at 10.8 m and I-10,213 at 10.7 m below ground surface elevation (g.s.e.), Middle Fork Tillatoba) and the disconformable contact between the younger valley-fill deposits and the >40,000 yr BP consolidated sandstone, all indicate appreciable valley

Table 5. Wood species by deposit.

Wood Identification			Frequency of Occurence (a)								
Species	Common Name	All deposits	U[b]	PSA	M-BA	CF	MS	B-T	CL	GS	CSS
Acer sp.	maple	4			2			2			
Betula nigra	birch	3						1	2		
Carya sp.	hickory	2			2						
Castanea dentata	chestnut	4			3	1					
Catalpa sp.	catawba	1			1						
Celtis occidentalis	hackberry	1				1					
Cercis canadensis	redbud	2			2						
	conifer	1									1
Diospyros virginiana	persimmon	1			1						
Fagus grandifolia	beech	9						2	5	2	
Fraxinus sp.	ash	7			2	5					
	hardwood	7	1		1	1			3		1
Juglans sp.	walnut	2			1			1			
Liquidambar styraciflua	sweet gum	6	1	2	3						
Liriodendron tulipifera	tulip-tree	5			2	1				2	
Pinus sp.	pine	1	1								
Platanus occidentalis	sycamore	8	1		2	1			3		1
Populus sp.	poplar	2	1		1						
Prunus sp.	cherry	1			1						
Quercus sp.	oak	39	3	3	15	4		5	9		
Rhamnus *caroliniana*	Carolina buckthorn	1			1						
Salix sp.	willow	2			1					1[c]	
Sassafras albidum	sassafras	2			1	1					
Taxodium distichum	bald cypress	3	1		1	1					
Ulmus sp.	elm	12	1		4	2		2	3		

(a) U = undifferentiated, PSA = postsettlement alluvium, M-BA = meander-belt alluvium, CF = channel fill, MS = massive silt, B-T = bog-type, CL = channel lag, GS = gray silt, CSS = consolidated sandstone.

(b) The ^{14}C ages of the undifferentiated samples ranged from <185 yr BP for the *Liquidambar styraciflua* sample to 33,200 yr BP for one sample of *Quercus* and >40,000 yr BP for the other two *Quercus* samples. Of the remaining 6 samples, 3 had ages equivalent to that of meander-belt alluvium, the *Pinus*, *Taxodium* and *Platanus* sps., and 3 had ages equivalent to that of channel-fill deposits, the *Populus* sp., *Ulmus* sp. and hardwood sample.

(c) Possibly *Populus* sp.

erosion prior to 12,050±180 yr BP. Additional data supporting valley erosion is the 13.4 to 13.7 m depth of the 17,050±350 yr BP sample (I-11,495, Tippah River), the 16.2 to 16.8 m depth of the 34,900±2100 yr BP sample (I-11,283, Yoda River) and the 5 to 7 m terraces present in several of the valleys along the bluff line. The ages of the terraces have not been established. Such valley erosion is logical, resulting from the interaction of post-glacial pluvial conditions (Fairbridge; 1970, 1972, 1976) with low (relative to present) base level controls. Although absolute base level controls are unknown, they can be estimated, relative to present conditions, from sea level and flood-plain elevation changes. Sea levels were lower about 12,000 yr BP with estimates ranging from about 25 m below present (Field et al., 1979 and Blackwelder et al., 1979) to about 75 m below present (Emery and Merrill, 1979). Flood-plain elevations for the Mississippi River were probably about 6 to 8 m below present in northern Mississippi (Saucier, 1974). Flood-plain elevations prior to 12,000 yr BP are poorly defined. It should be noted that this period of valley erosion in north-central Mississippi is comparable in age with a period of erosion documented by Ruhe (1969) in Iowa.

4.2.2 Bog-Type And Channel Lag Deposits

As used herein, bog-type sediments are fine-grained, organic-rich materials deposited from low-energy fluvial systems. Most of these deposits appear to have formed in either channel cutoffs or in separation zones downstream of point-bar deposits, along the inner bank of a bendway. We have used the term bendway rather than meander to avoid any implication that these materials were deposited by meander-type flow. We suspect the channels were braided at this time but have only indirect evidence (discussed in the next section). Channel lag materials are coarse-grained, frequently cross-bedded materials deposited from high-energy fluvial systems. Gravel is common where not limited by source availability. Both deposits contain abundant organics. In general, the organic debris in the lag deposit is relatively coarse, ranging up to 50 cm diameter logs. Bog-type organics include leaves, twigs, various nuts, and scattered stumps and logs similar in size to those found in the lag deposit. Typically the organics in both deposits show little evidence of abrasion or aerobic decomposition, indicating rapid burial. Heartwood, alburnum and bark are usually well-preserved and the cellular structure of woody tissue is

intact. In addition, acorns with caps attached; complete leaves; and walnuts, butternuts, and hickory nuts, frequently complete with husks have been seen in the bog-type deposit.

All samples of the bog-type and channel lag deposits have ages defined by the frequency mode about 10,000 yr BP (Fig. 17a). The age span of this mode is interesting; it is generally synchronous with the time man first appeared in the lower Mississippi River valley (Saucier, 1974) and with the time of excessive Pleistocene generic extinction (Grayson, 1977). We interpret this period as transitional between the preceding period of valley erosion and the subsequent period of deposition of fine-grained materials (see section 4.2.3). The range of individual ages for outcrop samples within this mode, 4580 ^{14}C yr (sample I-11,608, Hotophia Creek at 13,130±170 to sample I-10,955, Johnson Creek at 8,550±140 yr BP, Table 4), reflects both within-watershed variation and between-watershed variation. The twelve Johnson Creek samples within this mode had an age range of 2500 ^{14}C yr, and this range is interpreted as a time of complex response. Base level was relatively constant; depth below g.s.e. for these twelve samples ranged from 3.4 to 4.7 m. The four comparable Hotophia Creek samples were the four oldest samples within this mode and were an average of almost 1000 ^{14}C yr older than any other sample. This greater age for the Hotophia Creek samples is possibly related to the relative position of this creek in the drainage net of the Yazoo River system (Fig. 16). Hotophia Creek is a tributary of the Tallahatchie River, the major tributary within the Yazoo River system, and joins the Tallahatchie near the present Mississippi River Valley. As the major tributary within the drainage net of the Yazoo River system, the Tallahatchie River and its tributaries would respond rapidly to Mississippi River Valley base level controls. The average ages for samples in this mode are presented in Table 6. Qualitatively, these average ages from tributaries of bluffline watersheds decrease with decreasing watershed size (Tallahatchie>Yalobusha>Yocona). Tillatoba, however, is a bluffline watershed and samples from this location have average ages intermediate between tributaries of the Tallahatchie and Yalobusha watersheds. Due to the limited number of samples, these relations must be considered as preliminary trends. Sample depth, however, does reflect the overall significance of base-level as a control of the valley-fill sequence. In general, the sample depth decreased with increasing distance from the present bluff line.

4.2.3 Massive Silt, Channel Fill And Meander-Belt Alluvium

The massive silt and meander-belt alluvium developed in relatively fine-grained deposits, and both are buried beneath postsettlement (historic) alluvium. Each of these two units has a consistent set of depositional features and a distinctive, characteristic weathering profile. The properties of these two units have been produced by both depositional and weathering features. We refer to the weathering profile in the massive silt as paleosol II and that in the meander-belt alluvium as paleosol I.[3/] This designation minimizes possible confusion involving soil classification units and associated weathering features. These soil classification units are materially influenced by the overlying postsettlement alluvium.

4.2.3.1 Massive Silt: This unit is a widespread, predominately fine-textured, valley-fill deposit. This deposit is distributed throughout the study area and frequently exceeds 4 m in thickness. The deposit fines upward from a silty sand or sandy silt basal material to a silt, with no observable textural breaks except for occasional small relict channels. No large relict channels have been observed which would indicate channelized flow at this time of valley aggradation. Additionally no organics have been found in this unit and bedding is rare. Bedding has been observed only in the sandy basal material.

At places, a textural interface separates the overlying fine-textured deposit from a dense, fine-textured basal phase. Samples in the gray silt unit (I-11,558 and I-11,572, Johnson Creek), immediately below the basal phase, had ages within but on the young side of the mode at about 10,000 yr BP, suggesting that both the basal phase and the gray silt unit are intermediate in age between the massive silt and bog-type or channel lag deposits. The gray silt deposit was separated from the 21,250±450 yr BP

3/ The terms paleosol I or II are used in this appendix to unambiguously separate these weathering surfaces from the depositional units. In practice, this is a dual classification; paleosol I type weathering has always been observed to be developed in meander-belt alluvium and paleosol II type weathering in the massive silt. In other parts of this report, we have used the terms young paleosol and old paleosol. These are convenience terms referring to combined weathering and depositional features; the former denoting paleosol I type weathering in the meander-belt alluvium and the latter denoting the paleosol II type weathering in the massive silt.

Table 6. Average age of outcrop samples in the 10,000 yr BP mode for bluff line watersheds.

Main Stream (a) Intermediate Tributary Tributary	No. of Samples	Average Age ^{14}C yr BP	Distance From Bluff Line (b) km
Tallahatchie			
Hotophia	4	12,000	17
Yalobusha			
Topashaw	4	9,900	77
Yocona			
Peters			
Goodwin	2	9,600	16
Johnson	12	9,700	16
Tillatoba	5	10,300	10

(a) The term main stream is used to identify those streams which flow from the loess area into the alluvial valley of the Mississippi River. The relative watershed size for these streams is Tallahatchie>Yalobusha>>Yocona>>Tillatoba.

(b) Approximate distance.

organic sandy silt material (sample I-11,609) by a cross-bedded sand deposit, presumed to be the channel lag unit.

At most sites, the massive silt overlies bog-type and channel lag deposits which have an age of about 10,000 yr BP. At Johnson Creek, three samples at the contact between the massive silt and bog-type deposit had ages of about 8,700 yr BP (samples I-10,955; I-10,956; and I-10,965). Relict entrenchment into or through the massive silt deposit is common. Five wood samples (I-10,396, Perry Creek; I-10,694, North Fork Tillatoba; I-10,212, Middle Fork Tillatoba; I-9,914, Hotophia Creek; and I-10,395, Goodwin Creek) have been obtained at outcrops of such channel-fill deposits. These woods range in age from 4,050 to 6,120 yr BP, comprising the frequence mode at about 5,000 yr BP (Fig. 17a). Ages of comparable samples obtained during the drilling program indicate a somewhat greater span (Fig. 18b). The maximum age of all samples in this mode was 7,100±240 yr BP (sample I-11,251, Hotophia Creek). This sample establishes the absolute minimum age of the massive silt deposit at about 7,000 yr BP.

Based upon the absences of large relict channels, bedding and textural breaks, we interpret the massive silt as a low-energy fluvial deposit, possibly associated with periodic inundation resulting from valley plugging. Such plugging has been described by Pflug (1969) for tributaries in eastern Brazil, but at a slightly earlier time than that for this deposit. Aeolian materials may have been a secondary source for this massive silt deposit. The contact between the massive silt and channel lag deposits where present, is gradational, indicating that the silt is only slightly younger than the underlying deposits. We interpret this massive silt deposit as the end member in the sequence of valley erosion → channel lag or bog-type → massive silt, this sequence representing a continuing [illegible] energy resulting from decreasing pluvial activity and rising base level controls. Indirect support for this interpretation is contained in the late-Quaternary discharge record of the Mississippi River and in the p[illegible]ure record. Meltwater flow down the Mississippi River [illegible] about 17,000 yr BP. This flow increased steadily and peaked [illegible] 13,[illegible] yr BP at which time flow diversion occurred to the east via the St. Lawrence valley. Meltwater flow volume decreased rapidly until [illegible] yr BP when normal isotopic composition was restored (Kennett [illegible]ackleton, 1975). The paleotemperature record complements the flow

record. Temperature recovery started about 15,000 yr BP and was relatively rapid (Godwin, 1966; Harmon et al., 1979). By about 10,000 yr BP, meteoric water was comparable with that of today, based on D/H ratios (Yapp and Epstein, 1977), indicating effectively complete transition from glacial to interglacial conditions by this time. They describe this transition as asynchronous for North America. An alternate interpretation is that the silts represent vertical accretion deposits and the channel lag deposits represent lateral accretion deposits, both resultant from meandering stream flow. The vertical and lateral accretion deposits would generally be equivalent in age, using this alternate interpretation. We believe the first interpretation is most probable.

The paleosol II type weathering profile formed in the massive silt is distinctive. It possibly formed by ferrolysis-type weathering, as described by Brinkman (1970). This paleosol has a thick A_2 and a dense B_2 horizon, both unique to paleosol II. Gray is the dominant color in the upper part of the profile. Iron and manganese stains and concretions are present in the lower B. The B_2 horizon has a well developed polygonal structure, with seams often wider than 2 cm. These seams are frequently continuous from the typical massive silt deposit into the dense basal phase. This unit is relatively infertile and restricts the vertical movement of water. Vegetative cover is rare on outcrops.

4.2.3.2 Channel Fill: As noted previously, this deposit comprises the frequency mode at about 5,000 yr BP. Deposits are less extensive than those for either the massive silt or the meander-belt alluvium. Materials are typically sandier than those of the massive silt but have the same gray color. These materials are usually highly weathered, probably due to the sandy texture. They have no polygonal structure and no well-developed B_2 horizon. Bedding is frequently difficult to discern.

4.2.3.3 Meander-Belt Alluvium: A major entrenchment of streams into the massive silt began about 3000 yr BP (sample I-10,940, Johnson Creek). This time of entrenchment agrees with the paleoclimatic interpretation of Wendland and Bryson (1974) who reported a major botanic discontinuity at 2760 yr BP associated with increased rainfall. The distribution of ages in the youngest frequency mode (Fig. 17a) indicates that entrenchment in our study area was relatively minor until about 1600 yr BP. Activity increased gradually to a peak frequency in the 200 to 400 yr BP class interval (Fig.

18c). Again, the sample size and collection procedure does not preclude sample bias and this age distribution within the youngest mode should be considered a trend. The entrenching streams apparently meandered across the flood plains, eroding the massive silt and channel fill materials and depositing the unit identified as meander-belt alluvium (Fig. 19). These materials are typically vertical accretion overlying lateral accretion deposits with occasional oxbow deposits of layered fines.[4/] These two types of deposits have not been separated. Wood is scattered throughout this deposit but is usually not as well preserved as the older wood. This state of wood preservation is probably due to the greater permeability of this material relative to that of the massive silt. In all cases, bedding is readily observable.

Paleosol I weathering is less intense than that of paleosol II. Paleosol I has an A_1 which varies in thickness from more than 25 cm to only a few cm. In places, the profile is truncated with no observable A. Iron diffusion halos are usually present in the subsoil but are typically small. This unit has no A_2 horizon and no pronounced B_2 horizon, suggesting that it developed under grass cover. It has no polygonal structure, is relatively fertile and is well drained.

4.2.4 Postsettlement Alluvium

Postsettlment alluvium (PSA) produced in historic times largely by man's activities, caps almost all flood-plain surfaces. This material is frequently less than 1 m thick but may locally exceed a thickness of 3 m. Low terraces, if present in the study area, have been effectively hidden from observation during field reconnaissance by this deposit. The PSA has well preserved fluvial bedding features. It is unweathered with an Ap horizon directly overlying a C horizon. Iron diffusion halos have not been observed. Although this unit is too young to be identified by radiocarbon procedures, it is identifiable in the field by the presence of man-made artifacts above a disconformity. It has been the subject of many reports, including those by Happ (1968, 1970) and Trimble (1974).

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4. Measurements of secular variation have been attempted for varve-like oxbow deposits. Preliminary results show declination 10° to 30° East of North, suggesting secular variation may be a useful correlation tool in the absence of datable wood samples. These determinations were made by S. Bressler, U.S. Geol. Surv., Flagstaff, AZ.

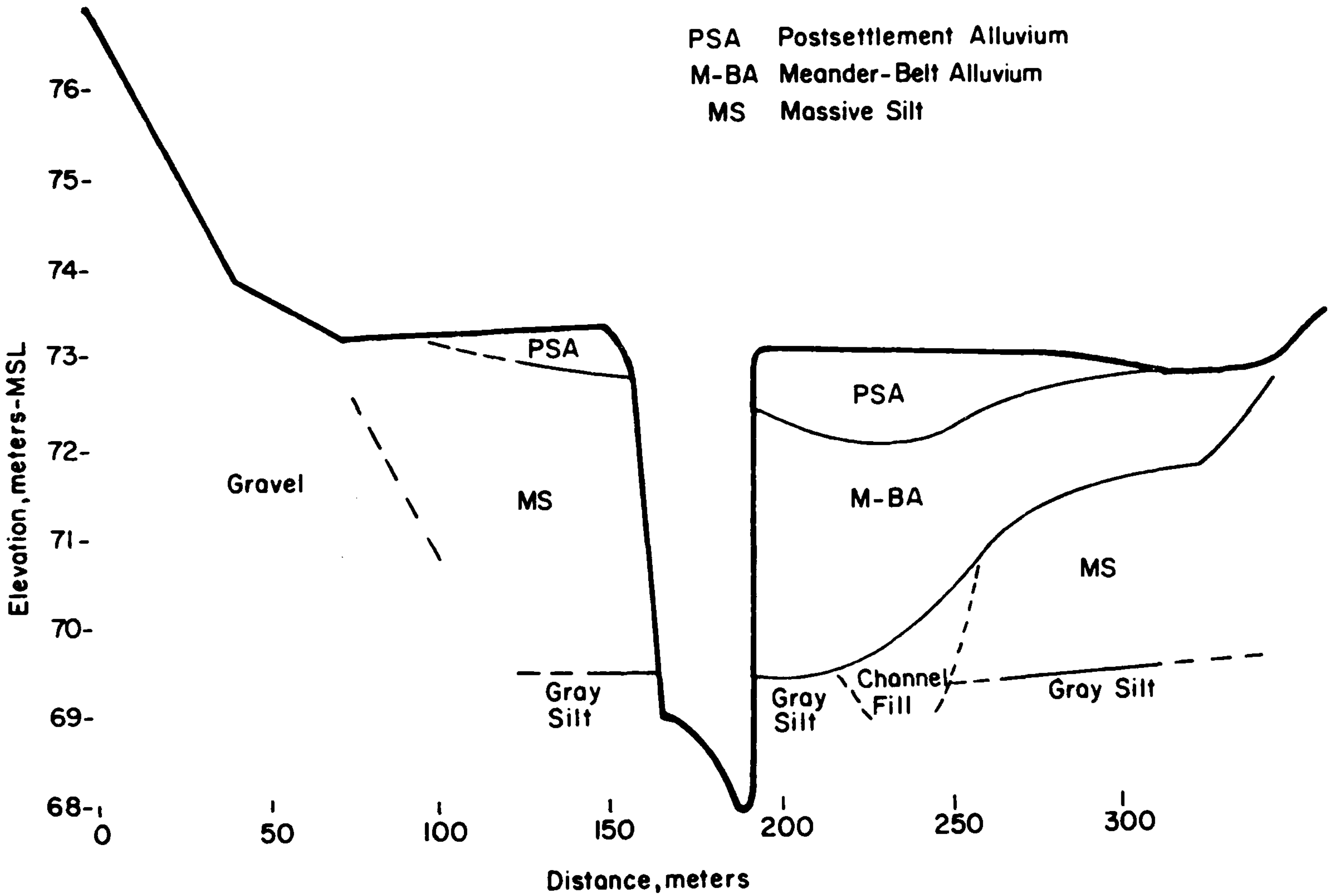


Figure 19 Distribution of valley-fill units in lower Goodwin Creek valley.

4.3 DISCUSSION

4.3.1 Paleoclimatic Control

Wendland and Bryson (1974) used 815 dates published in the journal Radiocarbon "-- to identify times of large-scale hemispheric discontinuity --" based on geologic-botanic discontinuities. Their data base included ^{14}C dates which defined the age of discontinuities within peat beds, pollen profiles, glacial records and sea level stands. A parallel data base included 3,700 dates associated with 155 cultures to identify cultural discontinuities. The primary source for these dates was also Radiocarbon. Globally synchronous discontinuities occurred in both records and they argued that such results could only be produced if climate was the primary forcing function. Of the seven major geologic-botanic discontinuities which they identified by fitting partial collectives to a multimodal distribution, three are included in the age range of 850 to 2760, one at 5060 and three in the range from 8490 to 10,030 yr BP. Fig. 17b is a frequency histogram of their total geologic-botanic data, organized in 800-yr classes to emphasize large-scale trends. The relation between the three groups of discontinuities and the age frequency for their data (Fig. 17b) is obvious, as is the similarity of this age frequency with (a) the times of isostatic rebound in the Great Lakes area (Fig. 17c) which Flint (1957) attributed to climatic control of glacial ice unloading and (b) the frequency for our data (Fig. 17a). The distributions are trimodal with (generally) comparable modal ages. This apparent fit supports Wendland and Bryson's argument that climatic change, and not any specific climate, is the primary forcing function. In relation to our valley-fill data, large-[illegible]matic changes would logically produce corresponding changes in [illegible] and these latter changes would, in turn, produce corresponding [illegible] [illegible]ley-fill deposits. A corollary of this reasoning is that [illegible] [illegible]alley-fill deposits are chronologic units if climate is the [illegible] function.

[illegible]ajor differences between Figs. 17a and 17b are (a) the younger [illegible] the most recent mode for our data, (b) the relatively small [illegible] the mode at about 5000 yr BP for our data and (c) the total [illegible]modal ag[illegible] for our data. We expected this latter [illegible] between the two distributions because of the restricted sample [illegible] source area of [illegible]. All of our samples were fluvial [illegible] from tributaries to the lower Mississippi River valley.

The relative difference in magnitude between the circa 5000 yr BP modes appears to fit a paleoclimatic trend of more uniform and drier conditions for our study area relative to that for Wendland and Bryson's data base. About 75% of their samples were European, a data base generally equal in origin to that of Starkel (1966). Knox (1975) compared these studies and reported that the results were also generally equal. According to Starkel, the Holocene Atlantic period (8150-4950 yr BP) in Europe was a time of climatic optimum. Mean annual temperature was about 2°C warmer than present and the climate was humid. Similar conclusions have been presented by Imbrie and Imbrie (1979), by Godwin (1966) and by Fairbridge (1976) who noted that the northerly shift of the optimum was strongly diachronous. The sub-Boreal period (4950 to 2450 BP) was markedly different (Starkel, 1966). It was warm but rather dry with pronounced fluctuations in humidity.

For the North American continent, however, climatic conditions were evidently somewhat different. Davis et al. (1980) found that the climate of New England from 9000 to 5000 BP was one of maximum warmth or warmth and dryness. During this time, the prairie-forest boundary of the upper Midwest (United States) was east of its present location, indicating warmer and drier conditions than at present (McAndrews, 1967). For both areas, the climatic change to present conditions was gradual. In the Lake Michigan Basin, the post-glacial warming continued until 3500 to 4000 yr BP (Zumberge and Potzer, 1956). This was the warmest and driest period during the Holocene for this area. In Iowa, the change from deciduous vegetation to nonarboreal species began about 7000 yr BP with the latter species becoming dominant about 6000 yr BP (Ruhe, 1969). Comparable climatic changes have been reported for many areas of the United States. Early-to mid-Holocene climates either warmer and/or drier than present have been reported for southeastern Missouri, from 8700 to 5000 yr BP (King and Allen, 1977); for middle Tennessee, from 8000 to 5000 yr BP (Delcourt, 1979); for northern Florida, from 11,000 to 7,200 yr BP (Watts and Stuiver, 1980); and for southern Florida, from 8000 to 4500 yr BP (Clausen et al., 1979). Climatic recovery to present conditions, if discussed in the preceding references, is usually described as gradual. In the southwestern United States, however, the climate has continued relatively unchanged since early- to mid-Holocene (Bryant, 1975 and Van Devender and Spaulding,

1979). We suggest that this subdued climatic change, in contrast to the relatively rapid transition or times of discontinuity characteristic of the European climatic sequences, is responsible for the relatively low magnitude of the mode at about 5000 yr BP for our data. The rationality for this suggestion is that the magnitude of complex response (Schumm, 1977) will probably vary directly with both the magnitude and rate of change of the forcing function, in this case climatic change.

The younger average age of the most recent mode for our data in relation to the comparable mode for Wendland and Bryson's data is not as easily explained. This difference may be due to sampling bias, or it may be related to paleoclimatic conditions in the mid-continental United States. Wendland and Bryson noted that the major botanic-geologic discontinuity at 850 yr BP coincided with a distinct change in the Mill Creek culture of Iowa. They hypothesized, based on pollen data, that this change resulted from stronger westerlies. Such a change in circulation patterns would have probably affected large areas of the mid-continental United States, possibly including northern Mississippi. For our study area, the increase in arboreal species, particularly the riparian species, present in meander-belt alluvium (Table 5) reflects a more humid late-Holocene paleoclimate relative to mid-Holocene conditions. This species diversification supports the previous interpretation based on wood frequency. The paucity of older ages within this mode is consistent with gradual climatic changes, as discussed previously.

4.3.2 Relations With Other Valley-Fill Deposits

Knox (1975) analyzed 802 dates from the journal Radiocarbon. This data base included dates of flood-plain horizons, terraces, alluvial fans [illegible] a few archaeological dates, in aggregate representative of Northern [illegible] ddle latitudes. His results were in good agreement with those of [illegible] and Bryson (1974) and Starkel (1966). He concluded that this ag[illegible]ent (a) "supports the concept of global synchroneity of climatic [illegible] b) "implies that alluvial episodes and the stability of stream [illegible] are strongly influenced by climatic change". Unfortunately, he [illegible] the percentage of European samples in his data base. The [illegible]nt of our results with those of Wendland and Bryson indirectly [illegible] milar agreement between Knox's analysis and our study. Direct [illegible]parison was not attempted.

Knox (1975) also discussed the results of Haynes' (1968) study of alluvial chronologies for the southwestern United States and reported that the discontinuities of the Southwest weakly reflected those presented by Knox, Starkel and Wendland and Bryson. Direct comparison of Haynes' results (1968) with ours is presented in Table 7. Although this comparison is subjective, it does suggest rather synchronous fluvial activity in these two areas. In Iowa, deposits have been identified with ages equivalent to the meander-belt fill. These deposits include the Turton, Mellinix and Hatcher members of the DeForest formation (Fig. 17e) (Daniels and Jordan, 1966; Ruhe, 1969). Although somewhat older, the Watkins and Soetmelk members (Fig. 17e) of the same formation appear to be equivalent with the massive silt. Gully cutting and filling in Iowa began about 6,500 yr BP (Ruhe, 1969), between the two times of deposition of DeForest formation members, and this activity may be equivalent with channel incision in north-central Mississippi which started about 7000 yr BP. Both the Soetmelk and massive silt are underlain in places by gravel. Brakenridge (1980) identified a comparable valley-fill sequence in Missouri including (a) aggradation ending about 8,000 yr BP, (b) a period of stability ending about 5,000 yr BP followed by rapid incision and (c) cyclic erosion-aggradation since that time. In southwestern Wisconsin, however, Knox and Johnson (1974) found no evidence of fluvial adjustment to climatic change since about 4400 yr BP, a time spanning deposition of meander-belt alluvium in our study area. The ages of older valley-fill deposits were synchronous for these two areas.

Ages of buried organics from Georgia (Staheli et al., 1977), Tennessee (Kellberg and Simmons, 1977), Alabama (Curren et al., 1976) and Oklahoma (Goss et al., 1972) generally fall within the modal ages of the frequency distribution (Fig. 17a) for our study area. An older sample, dated at 32,000 to 35,000 yr BP, was reported by Kellberg and Simmons (1977) for Tennessee but this material was from a terrace 17 m above the present flood plain. The numbers of dates and/or the descriptions of the valley-fill units in these studies are insufficient for a more detailed comparison, however. Delcourt et al. (1980) reported a different valley-fill sequence for Nonconnah Creek, extreme southwestern Tennessee. As previously discussed, they reported organics within several meters of the flood-plain surface with ages of 17,200 to 22,300 yr BP. No materials

Table 7. Comparison of alluvial chronologies in north-central Mississippi and the Southwest (Haynes, 1968)(a).

Southwest			North-central Mississippi	
Unit	^{14}C Age(b)	Unit Description	^{14}C Age (b)	Unit
A	>11,500	fluvial gravels to fines	8,500 to 12,500	bog-type and channel lag
B_2	about 7,000 to 11,000	massive to weakly-bedded silt	slightly younger than about 10,000	massive silt
C_2	about 4,000 to 6,000	channel fill incised into B_2 or massive silt	4,000 to 6,100	channel fill
D	about 2,000 to 4,000	variable	No comparable unit	
E	<1,500	variable, incised into older units	primarily <1,000	meander-belt alluvium

(a) The B_1 and C_1 units of Haynes have been exluded from this comparison. The C_1 is an aeolian unit and the B_1 is described as usually local in extent.

(b) ^{14}C age in yr BP.

equivalent with the massive silt of our study area were described at this site. We suspect these differences resulted from varying base-level controls for these two areas. Nonconnah Creek drains into the Mississippi River via an oxbow lake near Memphis, Tennessee. This location has been a fulcrum of changes in the flood-plain elevation of the Mississippi River over the past 12,000 years. Saucier (1974) describes the flood-plain of 12,000 years ago as (a) probably 23 to 24.5 m lower than present south of Baton Rouge, Louisiana; (b) probably 6 to 8 m lower between Vicksburg, Mississippi and Memphis, Tennessee and (c) higher than today north of Memphis. With this rather constant base level control at Memphis, Nonconnah Creek valley would not have been subjected to the same degree of stress as was imposed on areas to the south, and such stress must have postdated the 17,200 yr BP deposit in the Nonconnah Creek area. This maximum age of 17,200 yr BP for valley erosion is in agreement with the paleotemperature inferences, with the increased discharge of meltwater in the Mississippi River and with general late-Quaternary glacial conditions. Older periods of lower base-level controls, relative to present controls for the Lower Mississippi River Valley, are suggested by (1) the greater depth (13.4-13.7 m) of the 17,050 yr BP sample (I-11,495) from Tippah River, relative to the depth of comparable age materials at Nonconnah Creek and (2) the excessive depth of sample I-11,283 (Yoda Creek, Calhoun County) which was dated at 34,900 yr BP. This sample depth below flood-plain elevation was 16.2-16.8 m compared to the terrace position of comparable age samples for the Tombigbee River (sample I-11,629), the Tennessee River (Kellberg and Simmons, 1977) and the Boyer River, Iowa (Ruhe, 1969). Inherently, subsequent valley aggradation would depend upon the degree of degradation. We interpret the brown silt, although undated by Delcourt et al. (1980), as equivalent with meander-belt alluvium of our study arc This material was present immediately below modern sediments.

4.4 CONCLUSIONS

We have identified seven late-Quaternary valley-fill units which regularly crop out in channels of our study area. Diagnostic properties are consistent within units and are sufficiently different between units to be usable in the field. The ages of these units have been established by dating 60 organic, outcrop samples using standard ^{14}C dating procedures.

These ages are coherent within units but differ between units representing different periods of fluvial activity. The properties of the units, their distributions in the valleys and their ages are consistent with the paleoclimatic record and the record of changes in base level control (for our study, changes in the elevation of the Mississippi River flood plain).

5 CHANNEL STABILITY

The late-Quaternary valley-fill units, together with present hydrologic conditions, control present-day channel stability in this study area. These units exhibit typical types of failure, depending upon their position in the channel bank and/or bed and these types of failure, in turn, depend upon both depositional and weathering properties. Bank stability is influenced by postsettlement alluvium, meander-belt alluvium, the massive silt and the bog-type and channel lag deposits. Bed (thalweg) stability is influenced by the massive silt, bog-type and channel lag deposits and the consolidated sandstone. Although discussed separately, bank stability cannot be evaluated independent of bed stability; both must be considered for realistic solutions to the massive channel instability problems of the areas bordering the Lower Mississippi River Valley.

5.1 BANK STABILITY

Postsettlement and meander-belt alluvium most frequently occur in an upper-bank position. These materials are well drained, relatively fertile and are usually well vegetated. Scour by high velocity flow is a minor consideration for stability due to the vegetative cover and the infrequency of exposure to such flow. Scour is proportionately more significant for these materials in a lower-bank position. The most frequent erosion problems result from gravity failure accentuated by tension crack development. These tension cracks are vertical and parallel to the channel bank. Their development is undoubtedly related to the minimal weathering, typical of paleosol I, and hence isotropic nature of these deposits.

Paleosol II developed in the massive silt has a distinctive polygonal structure which controls stability. Although individual blocks are resistant to channelized flow, the seam materials are only marginally stable. Erosion of the seam material reduces interped strength, resulting in gravity-induced block failure. We believe this polygonal structure is probably the result of desiccation due to the combined effects of the early- to mid-Holocene hydromorphic conditions and temperature maximum. As such, paleosol II is a relict of early-Holocene weathering. (As previously discussed, evidence for this temperature maximum is widespread but we have no such record for our study area.) Although failure of both fine-textured units is gravity induced, removal of the slough material is undoubtedly

controlled by weathering (break-up) of the slough blocks and by flow parameters. An additional influence of paleosol II on stability results from the low relative permeability of the B_2 horizon. This horizon is less permeable than the overlying materials and seep commonly occurs at the interface, further stressing stability of the overlying materials.

The bog-type and channel lag deposits underlie the massive silt. Both are unconsolidated materials of low cohesion and are easily eroded by channelized flow. Channel incision into either of these units invariably results in excessive channel widening due to excessively weak toe conditions.

5.2 BED STABILITY

Thalweg incision through the massive silt has occurred by headward migration of knickpoints. Two types of migration have been observed, the usual overfall-type failure and a more complex type of failure which is initiated by the development of chutes through the polygonal-structured paleosol II materials. Weak seam materials between individual blocks are winnowed by base flow, structurally isolating individual blocks which are easily displaced by high velocity flow. A variant of this latter type of knickpoint movement is illustrated in Fig. 20. Bed elevations were temporarily stabilized at outcrops of the polygonal-structured basal phase of the massive silt. Blowouts occurred between these outcrops, enlarging the channel width and, in many instances, deepening the channel bed below downstream thalweg elevations. The individual sills failed by chute development followed by widening, resulting in "apparent" headcut migration. This type of failure, by blowout, is difficult to identify from [illegible] data but can be identified on aerial photographs by noting discrete [illegible] channel widening in otherwise stable reaches. The hydraulic [illegible] of this type of knickpoint migration have not been studied. Such [illegible] may be significant in the long-term performance of low-drop [illegible] particularly the features concerned with blowout depth.

[illegible]r Johnson Creek, the rate of knickpoint movement averaged 160 m/yr [illegible] through 1975, Fig. 21 (Ethridge, 1979). Thalweg elevations [illegible] of such knickpoints were generally stable except for the [illegible] discussed blowouts. Channel beds were cohesive and width-to-

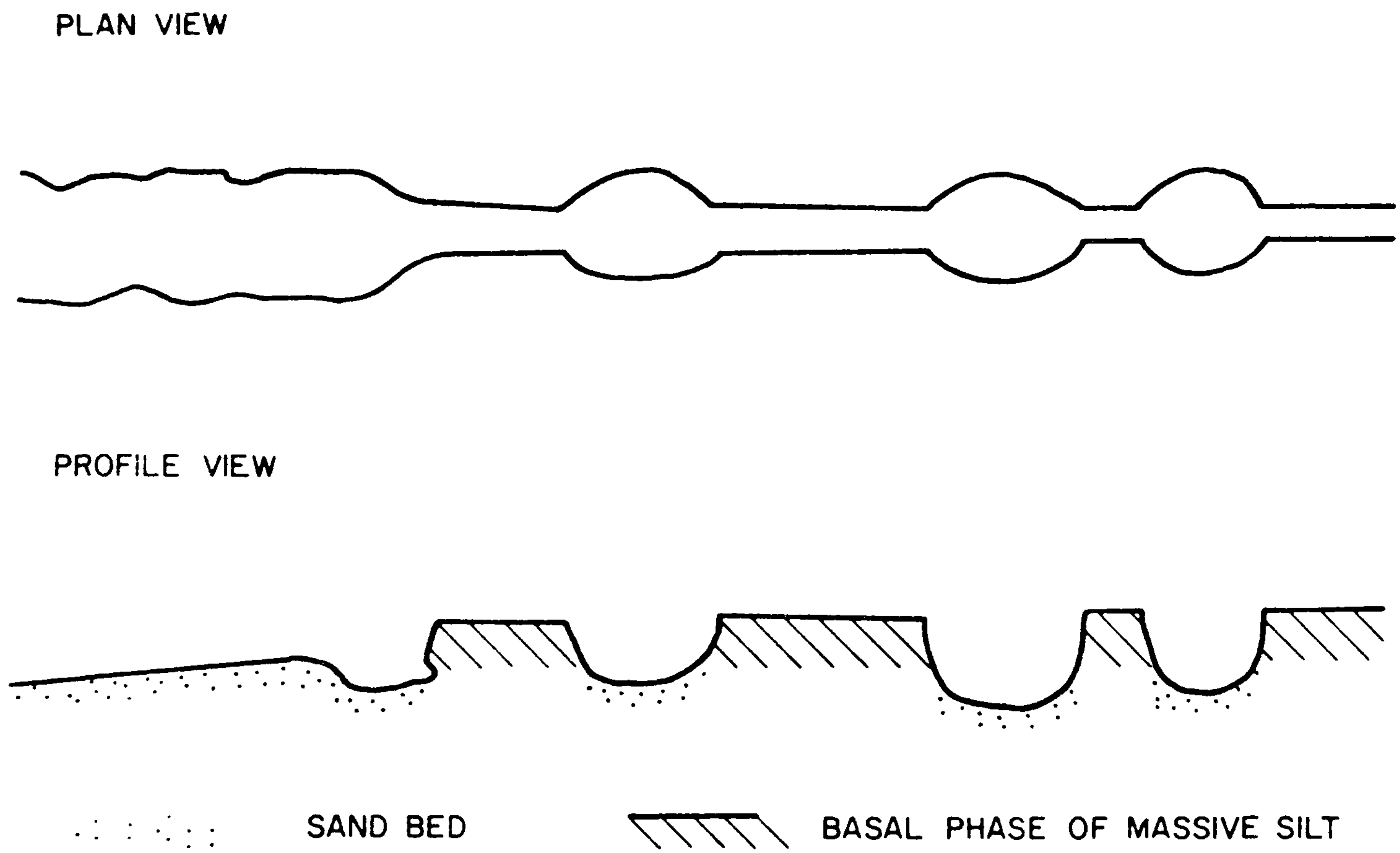
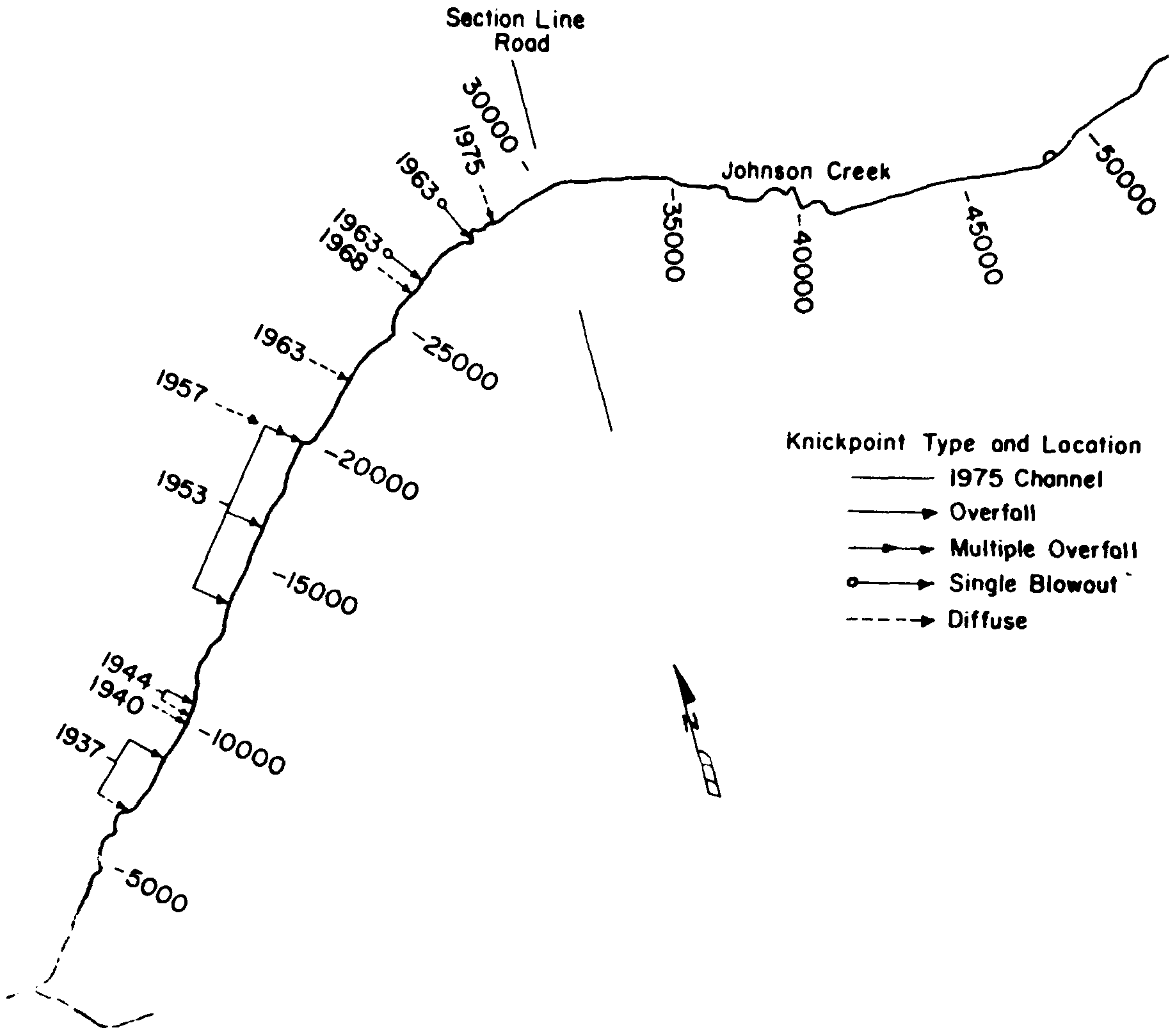


Figure 20 Blowout-type thalweg lowering between outcrops of basal-phase massive silt, upper Johnson Creek.



... n Creek (after Ethridge, 1979).

depth ratios were consistent (Fig. 22a[5/]). Exposure of the unconsolidated bog-type and channel lag deposits downstream of the knickpoint, however, resulted in channel widening and changed the flow regime. Downstream, the channels have sand to gravel beds with variable width-to-depth ratios (Fig. 22b[5/]). Transport processes are dominant. Inherently, the bed stability of these sand-bed channel reaches is primarily dependent upon sediment supply to and transport properties of the hydraulic system. Consolidated sandstones, such as those which outcrop in Goodwin Creek channel, limit thalweg lowering; they function as local grade controls. Width-to-depth ratios for Goodwin Creek are similarly variable, in this case due to excessive widening (Fig. 23[5/]). Excessive channel changes were determined for both channels for the period preceding the 1975 aerial photographs.

5.3 CONCLUSIONS

These process units function as stratigraphic controls for channel adjustment to changing flow conditions. The consistency between our results and the base level and paleoclimatic records indicates that the valley-fill stratigraphic controls for a few channels may be usable as "model" controls for a much larger area. We think these findings have potential practical application in the management of our streams and rivers.

5/ Each data point in Figs. 22 and 23 is a measurement at a point location along the channel. The parallax method was used for this photogrammetric interpretation of aerial photographs for the years 1937, 1940, 1944, 1953, 1957, 1963, 1968 and 1975.

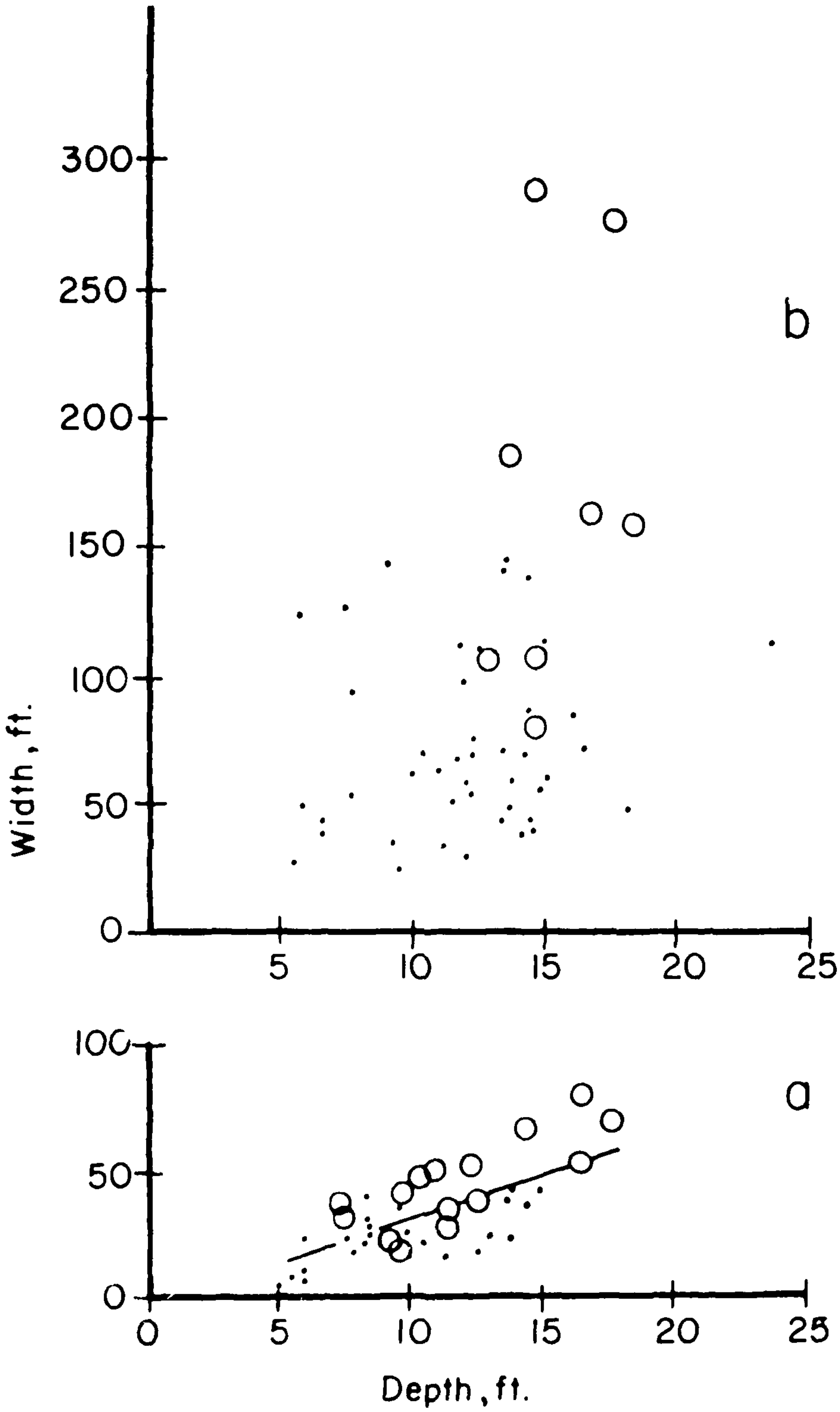


Figure 22 Width-to-depth ratios for Johnson Creek upstream (a) and downstream (b) of the knickpoint, from stereoscopic analysis of ASCS aerial photographs for the years 1937, 1940, 1944, 1953, 1957, 1963 and 1968 (identified by dots) and for the year 1975 (identified by circles)(Ethridge, 1979).

6 CHANNEL MORPHOMETRY

6.1 INTRODUCTION

As stated in the preceding section, the data presented in Figs. 22 and 23 are point values of width and depth. The data was collected by stereoscopic analysis (the parallax method) using ASCS aerial photographs for the years 1937, 1940, 1944, 1953, 1957, 1963, 1968 and 1975. In 1977, the channels were surveyed and flown for photographic record by the Vicksburg District, Corps of Engineers. Fig. 24 is the plan view of Goodwin Creek drawn from this 1977 photographic record. The main channel has been divided into 29 reaches (1 through 18 and 18-1 through 18-11) based upon the location of survey cross sections and upon "apparent" channel morphology. Most individual reaches include multiple cross sections. Average widths and depths for each reach have been calculated from the survey data and are listed in Table 8 along with standard deviations and maximum and minimum widths and depths.

6.2 WIDTH-DEPTH RELATIONS

Channel widths for Goodwin Creek are variable both between reaches and within reaches. The coefficient of variability (100 x standard deviation/average width) for individual reaches ranged from 11 to 72%. The average coefficient of variability for all reaches was 24%. Channel depth was less variable, having an average coefficient of variability of 7.5%. This degree of variability for individual measurements, particularly for channel width measurements, is accordant with the photogrammetric results presented in Fig. 23. Individual measurements of channel widths and depths show no consistent relation. Similarly, average widths and depths per reach show no consistent relation (Fig. 25). Field reconnaissance, however, had established three process controls of channel morphometry for Goodwin Creek and the average values of channel width and depth have been organized into three groups based on these three controls (Fig. 26).

A knickpoint was present at the downstream end of reach 8 at this time (1977), separating the two downstream groups. Paleosol II materials were more or less continuous immediately upstream of this knickpoint but were absent in a downstream direction. Reaches 1 through 7 comprise the channel length characterized by an absence of stratigraphic controls of bed elevation. The correlation coefficient for this group is significant but

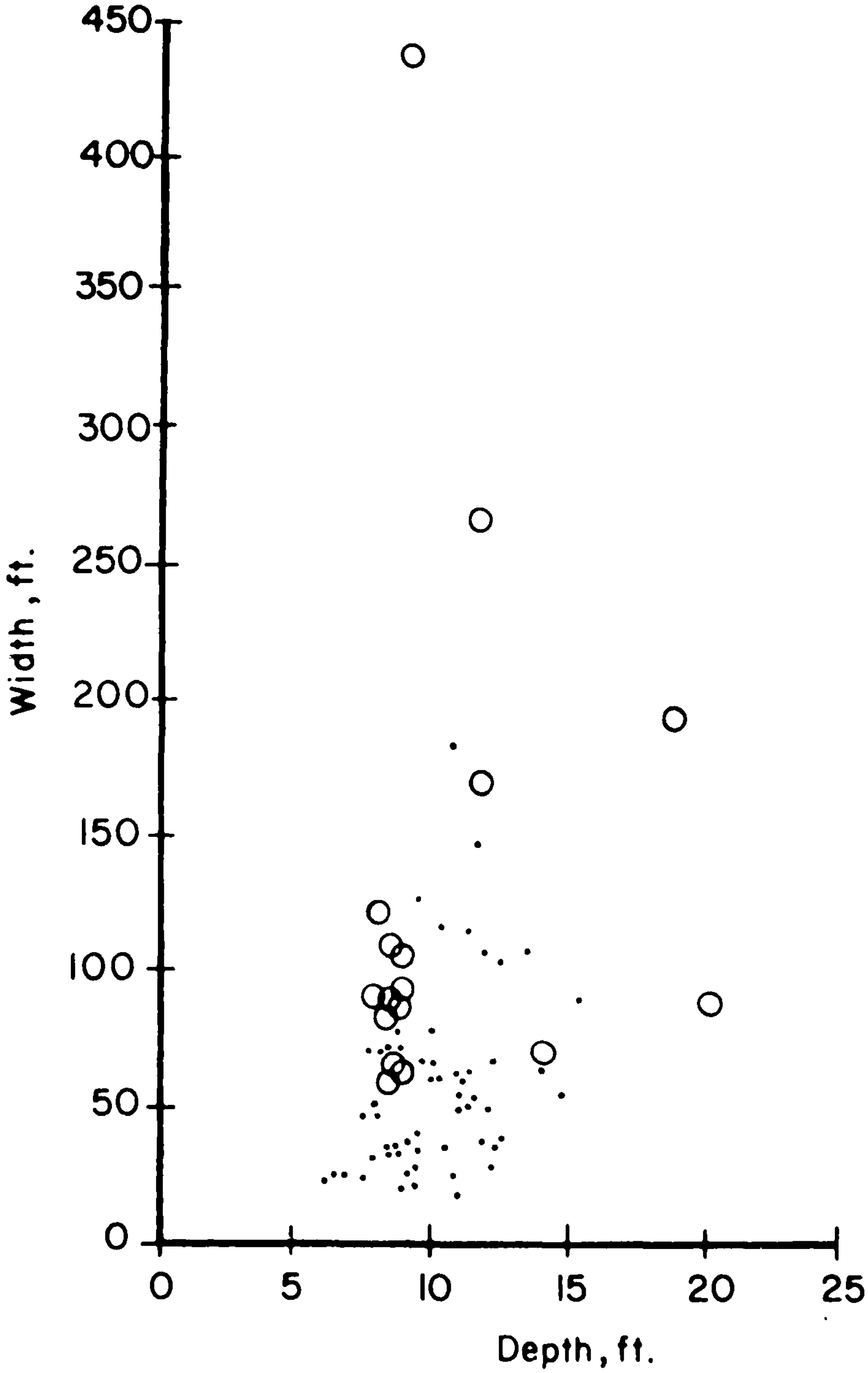


Figure 23 Width-to-depth ratios for Goodwin Creek, from stereoscopic analysis of ASCS aerial photographs for the years 1937, 1940, 1944, 1953, 1957, 1963 and 1968 (identified by dots) and for the year 1975 (identified by circles)(Ethridge, 1979).

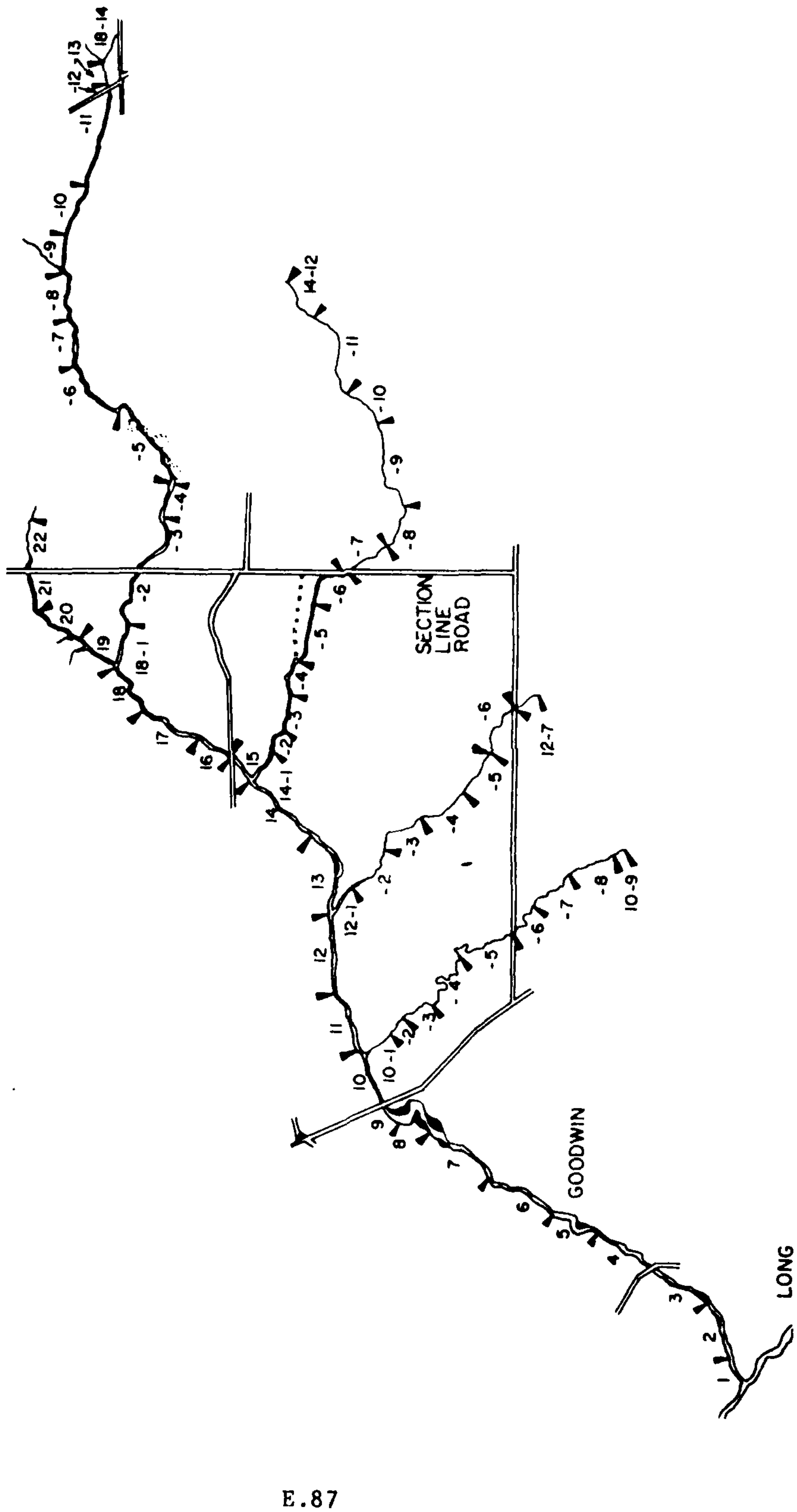


Figure 24 Goodwin Creek reaches.

Table 8 Width and depth of Goodwin Creek by reach, from 1977 survey.

Reach	Width, ft.				Depth, ft.			
	Max.	Min.	Average	Deviation	Max.	Min.	Average	Deviation
1	112.8	92.3	103.8	10.6	20.4	19.1	20.0	0.6
2	100.5	61.5	89.8	16.2	19.1	18.2	18.6	0.4
3	169.2	86.2	111.8	31.0	19.8	18.6	18.9	0.5
4	210.3	87.2	148.0	48.0	19.5	15.3	17.1	1.5
5	188.0	101.5	167.0	37.0	15.2	10.1	13.5	2.0
6	141.5	94.4	120.5	19.5	15.7	14.3	15.0	0.6
7	291.3	82.0	182.7	77.4	14.0	9.4	12.1	1.9
8	445.1	333.3	383.1	55.9	13.5	9.8	11.8	1.7
9	225.6	67.7	123.4	88.6	11.7	9.6	10.8	1.1
10	128.2	61.5	85.9	27.2	11.6	9.9	10.9	0.7
11	118.0	89.2	109.5	13.6	11.4	10.8	11.2	0.3
12	133.3	66.7	92.3	25.9	11.9	10.6	11.4	0.5
13	123.1	66.7	96.1	21.8	12.9	11.2	11.6	0.6
14	112.8	62.6	87.2	18.8	12.5	9.7	11.1	1.0
15	79.0	61.5	69.1	9.0	12.3	10.4	11.4	1.0
16	102.6	63.6	81.3	19.2	13.3	9.1	11.7	2.0
17	86.2	63.6	70.3	10.6	12.4	10.1	10.8	1.1
18			109.0				11.6	
18-1	80.0	47.0	63.2	14.3	14.0	12.0	13.0	1.0
18-2	141.5	68.7	97.5	32.8	16.6	12.9	14.3	1.4
18-3	148.7	69.7	97.2	30.3	14.8	9.3	13.1	2.3
18-4	116.2	80.0	103.0	17.1	14.4	13.2	13.8	0.6
[illegible]	[illegible]	50.0	73.9	12.9	15.8	15.0	15.4	0.4
18-6	90.0	55.0	72.8	13.2			15.0	
18-7	127.0	65.0	88.3	33.7	15.2	15.0	15.1	0.1
18[illegible]	118.[illegible]	45.1	85.1	26.4	17.3	15.4	16.0	0.9
[illegible]	61.5	51.3	58.1	5.9	18.0	16.6	17.4	0.7
[illegible]	66.7	51.3	60.0	6.5	19.6	18.2	18.8	0.6
[illegible]1	71.8	53.0	64.8	7.4	23.8	20.0	22.1	1.6

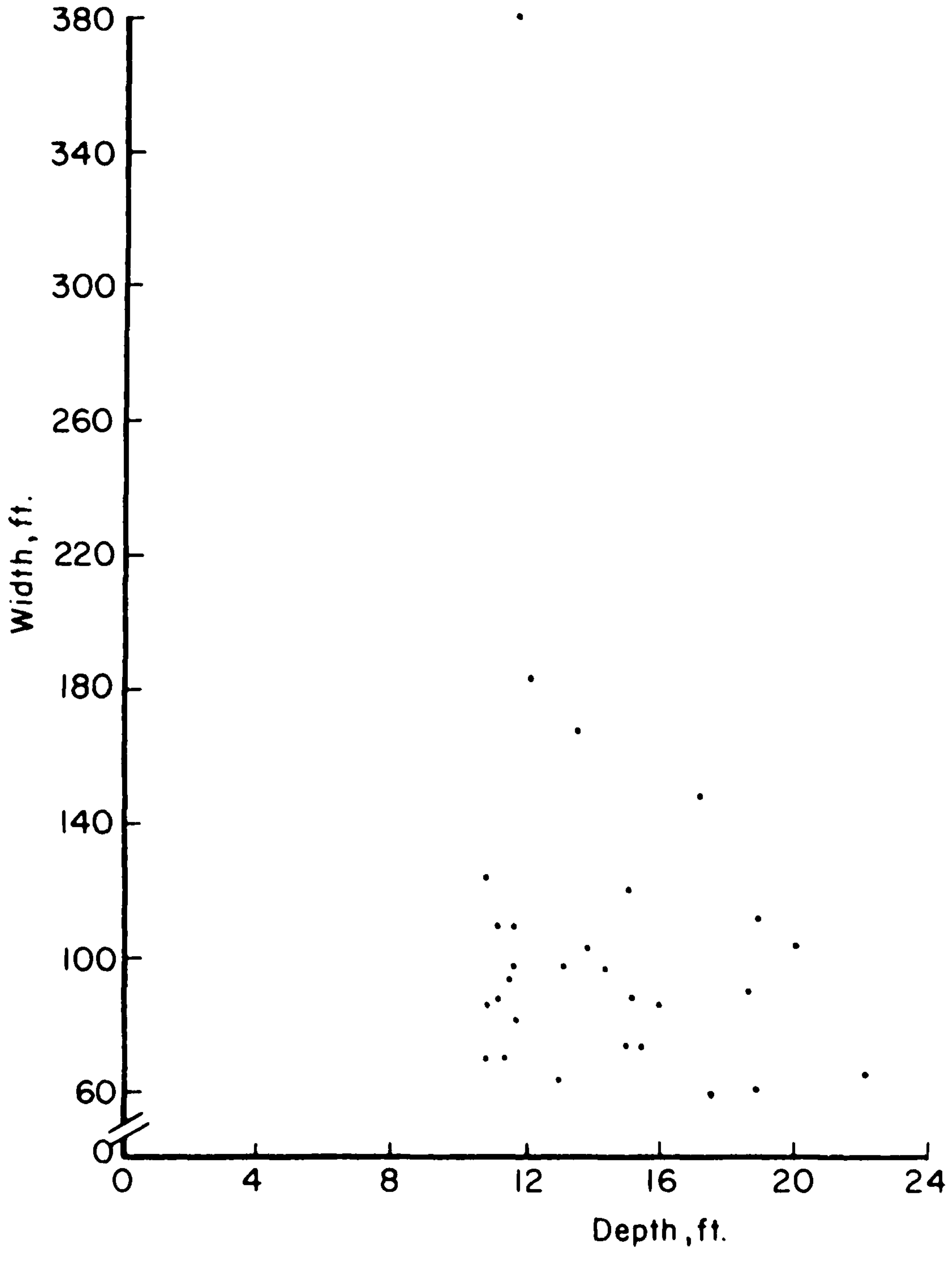


Figure 25 Average widths and depths for Goodwin Creek reaches, from 1977 survey.

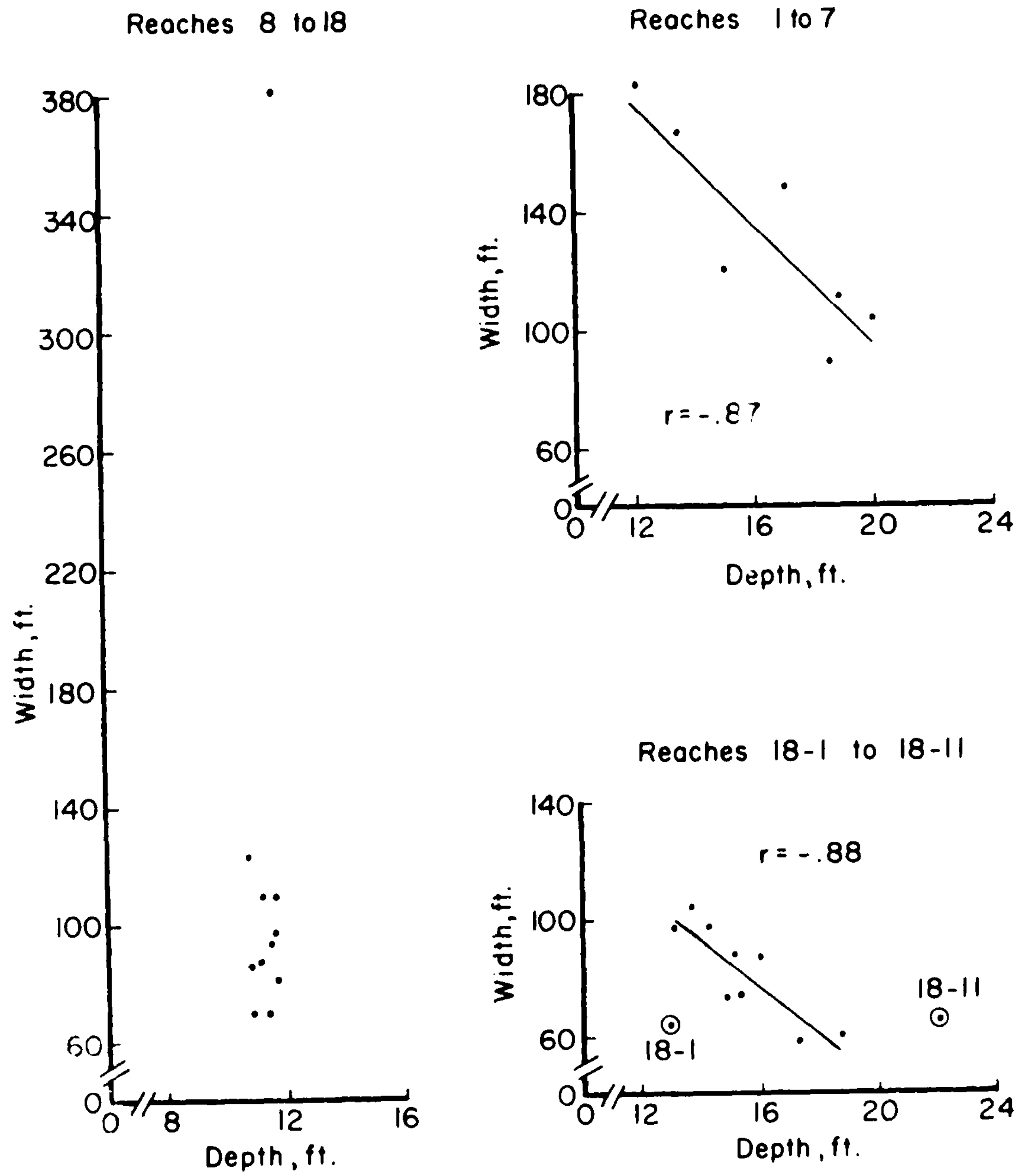


Figure 26 Average widths and depths for Goodwin Creek reaches by process control groups, from 1977 survey.

negative. Upstream of the knickpoint at reach 8 through reach 18 the channel width is independent of channel depth. Through this length of channel, the thalweg elevation has been stabilized by paleosol II materials, cemented gravel sills and numerous iron-cemented sandstone sills. Gravel bed material is common between outcrops of the bed controls and this gravel has probably lessened the failure rate for the controls, that is by lessening the probability of undercutting of the bed controls. Upstream of reach 18, the channel bed and bank materials are (stratigraphic) units considerably older than the Holocene valley-fill materials. These older units are facies of the terrestrial deposits disconformably overlying the paleosurface developed on the "Zilpha" formation (discussed in section 3.1). Outcrop units include "Tallahatta" layered fines to cross-bedded sandstones indurated during previous periods of weathering. These cross-bedded sandstones are bedded to the east and are capped by Roxana loess indicating a Sangamon age of weathering. These materials are lithologically different from bed and bank materials downstream of reach 18. For this headward-most length of channel, reaches 18-2 through 18-10, the correlation coefficient is significant and negative. Reaches 18-1 and 18-11 were not included in this calculation; the former reach is transitional between the two groups and the latter reach is biased by a road-culvert control.

Iron-cemented sills crop out in several of these headward-most reaches but occur at greater depths below ground surface than similar outcrops downstream. Additionally, thalweg slopes are generally greater for this headward-most length of channel. These two features limit the influence of the iron-cemented sills as morphometric controls.

6.3 SINUOSITY RELATIONS

For Johnson Creek upstream of the knickpoint, channel width and depth have a positive relation (Fig. 22a). Channel width increases as depth increases. This relation is logical for channels that are adjusting, enlarging, in a uniform manner to some new regime. The two significant correlation coefficients for Goodwin Creek (Fig. 26), however, are both negative. Width-to-depth relations are not simple in this case but involve a more complex relation with channel sinuosity (Fig. 27). Width-to-depth ratios increase with increasing sinuosity for reaches 18-1 through 18-11. This sinuosity is associated with meanders that have minimum present-day

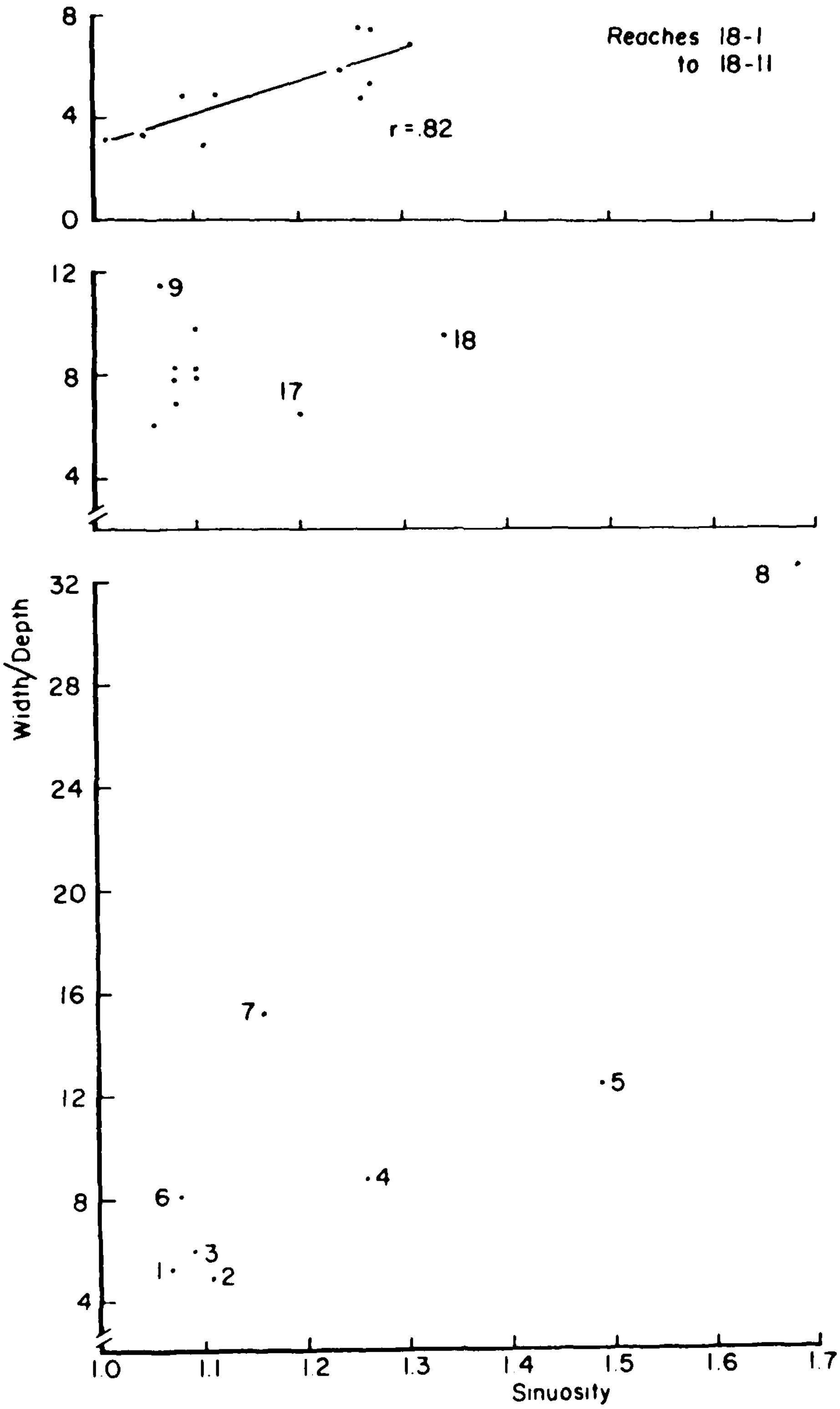


Figure 27 Width/depth ratios versus sinuosities for Goodwin Creek reaches by process control groups, from 1977 survey.

lateral movement. For reaches 1 through 8, two relations are obvious. The width-to-depth ratio increases from reach 1 to reach 5 which is typified by an exceptionally large bendway (Fig. 24). A similar sequence is obvious for reaches 6 to 8. As previously noted, channel width was independent of channel depth for the middle reaches and the width-to-depth ratio for these reaches is independent of sinuosity.

Sinuosity has no obvious relation with thalweg slope for Goodwin Creek in general (Fig. 28). As used in this discussion, the thalweg slope is the difference in elevation from the upstream to the downstream end of the reach divided by the thalweg length. The two large bendways, in reaches 5 and 8, however, apparently induce some local control of thalweg slope (Fig. 29). These bendways are both atypical of channel conditions in the lower reaches of Goodwin Creek. As such, they may impose excessive resistance to flow primarily as they induce secondary circulation. This effect of bendways and meanders in general has been discussed by Ackers (1980) and Hickin (1978). Hickin (1978) reported as much as an 8-fold increase in flow resistance for meanders relative to downstream relatively straight reaches of the Squamish River, British Columbia. Hickin (1978) and Bathurst et al. (1979) both discuss the significance of secondary flow associated with bendways. For Goodwin Creek, the thalweg slope of reach 4 is greater than that immediately upstream or downstream. Reach 5, immediately upstream, contains one of the exceptionally large bendways. This bendway has developed by erosion of relatively weak channel-fill material exposed on the bank. It has migrated 81 feet downstream in the last 3 years. A similar sequence is associated with the bendway at reach 8 but is confounded by the knickpoint at the lower end of this reach. The thalweg slope for reach 8, presented in Fig. 29, has been reduced by an amount equivalent with this drop and is identified as 8a. This adjustment results in the same sequence as described for the bendway at reach 5. This bendway at reach 8 was present on the 1937 photographic record but has meandered considerably since that time.

We speculate that these large bendways induce excessive, atypical flow resistance sufficient to disrupt the movement of coarse sediment through the bendways. The coarse sediment is stored as point bar materials at the bendways and as bed material immediately upstream. This sediment accumulation controls the thalweg slope upstream of the bendway. Downstream of the bendway, the flow is sediment-deficient resulting in bed

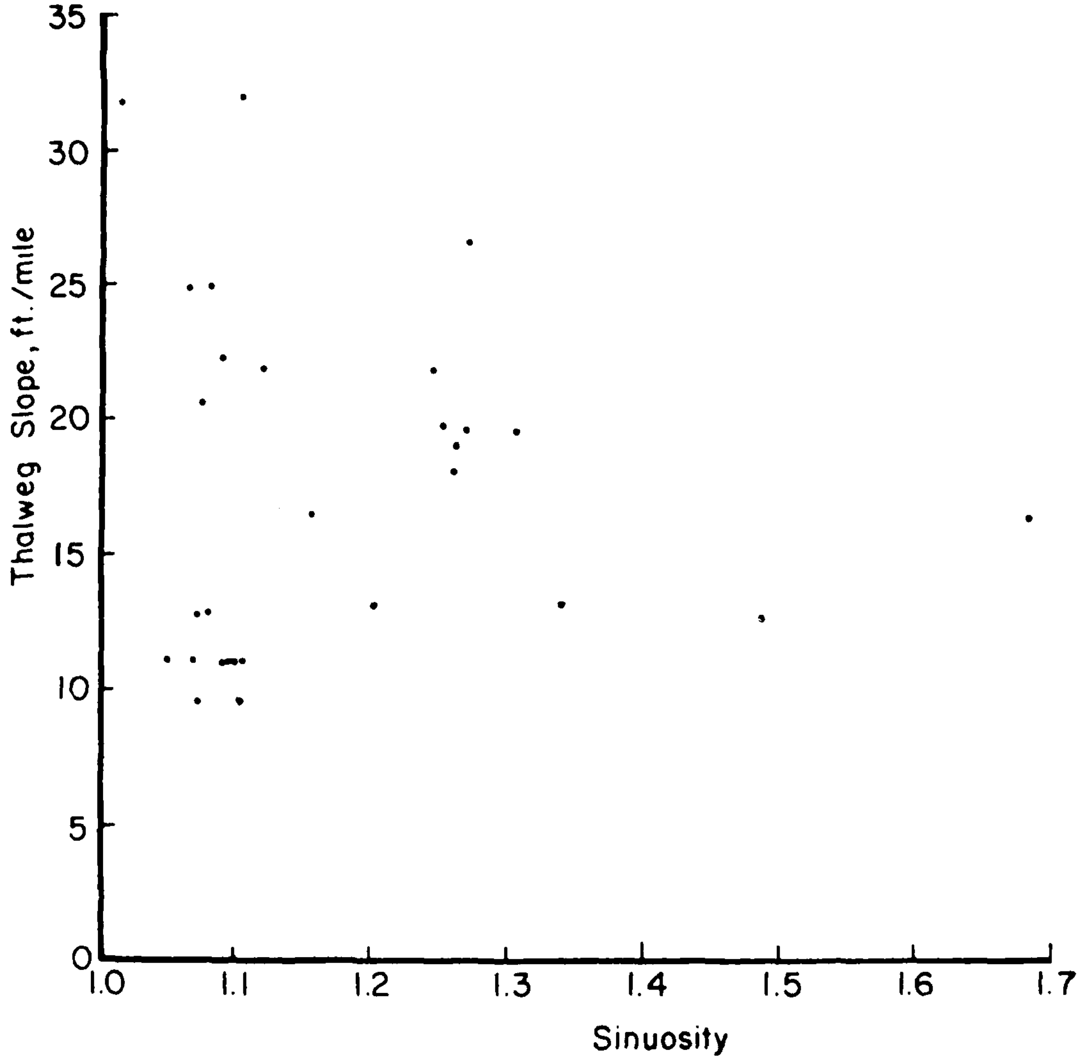


Figure 28 Thalweg slopes versus sinuosities for Goodwin Creek reaches, from 1977 survey.

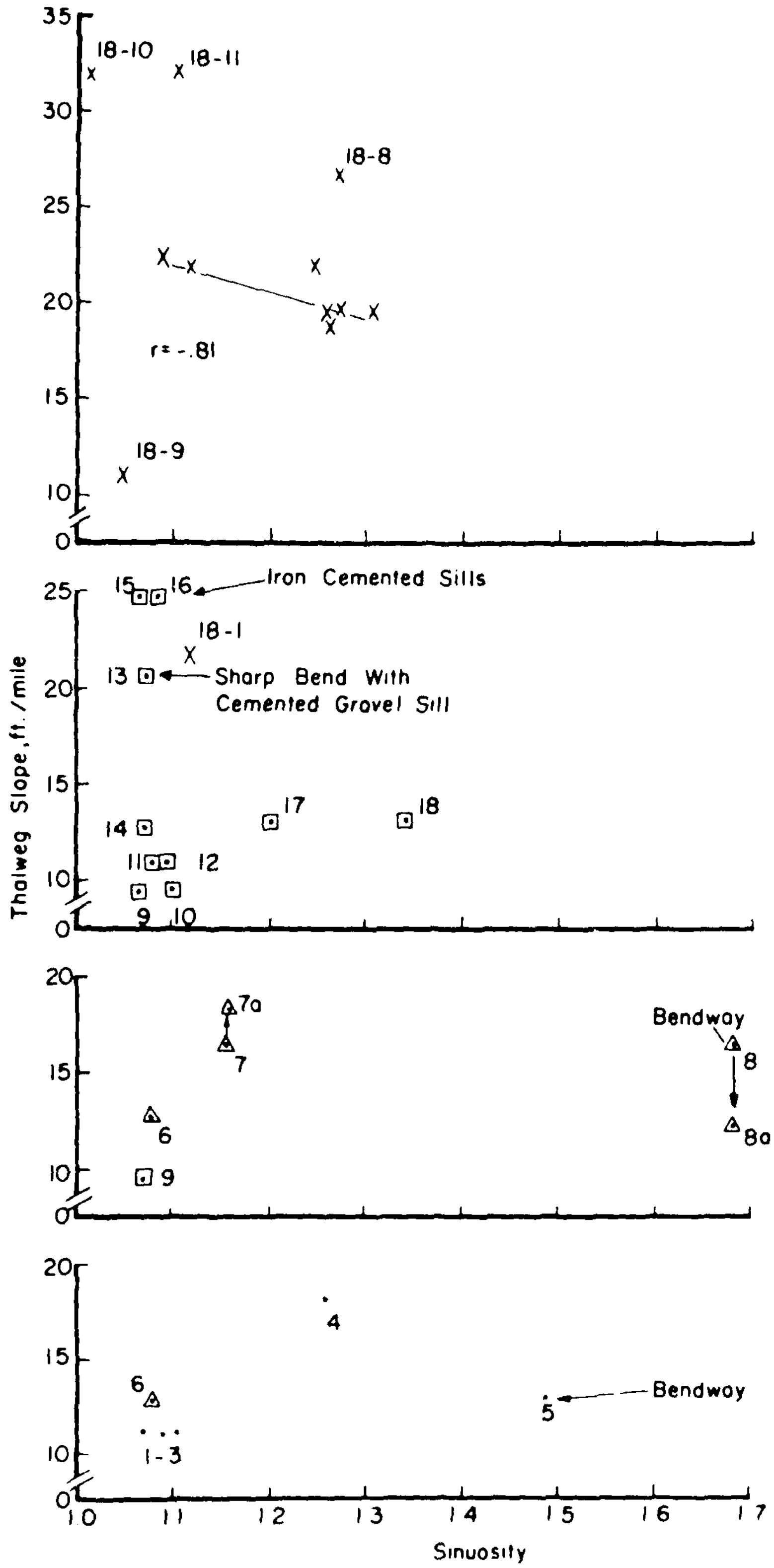


Figure 29 Thalweg slopes versus sinuosities for Goodwin Creek reaches by process control groups, from 1977 survey.

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erosion and greater thalweg slopes. It is interesting to note that reaches upstream of the large bendways are presently stable and the banks are typically well-vegetated. This observation includes the reaches upstream of the bendways at reaches 5, 8 and 18.

The iron-cemented sandstone and cemented gravel sills produce a comparable change in thalweg slopes. Such sills are present in reaches 13, 15, 16, 18-8, 18-10 and 18-11 (Fig. 30). These sills are effectively low-drop structures with overfalls, in some cases approaching 2-feet in relief. Reaches containing sills, therefore, have excessive thalweg slopes whereas reaches upstream of such sills have atypical low thalweg slopes. These sills have no observable relation with sinuosity.

6.4 DISCUSSION

Rivers may be classified according to various schemes. The most frequent classification is probably that of dividing rivers into two groups, alluvial and bedrock-controlled. Schumm (1977) summarizes this classification as follows.

> "All rivers may be separated into two major groups depending on their freedom to adjust their shape and gradient. Bedrock-controlled channels are those so confined between outcrops of rock that the material forming their bed and banks determines the morphology of the channel. Alluvial channels, on the other hand, are free to adjust dimensions, shape, pattern, and gradient in response to change, and they flow through a channel with bed and banks composed of the material transported by the river under present flow conditions."

Relations between hydraulic properties and morphometry of alluvial channels have been studied extensively and have been incorporated into various regime-type equations such as those discussed in Chapter 2 of the Comprehensive Report. For the time constraints of this applied study, however, Goodwin Creek and possibly many of the Bluff Area streams are really intermediate between these two groups. These channels are "--free to adjust dimensions, shape, pattern and gradient--" but not in the time frame inherent for channel stability studies. (See Church (1980) for additional discussion.) Schumm and Lichty (1965) address this problem of time and conclude that the dependence or independence of variables is governed by time-scale considerations. For this study of the Goodwin Creek

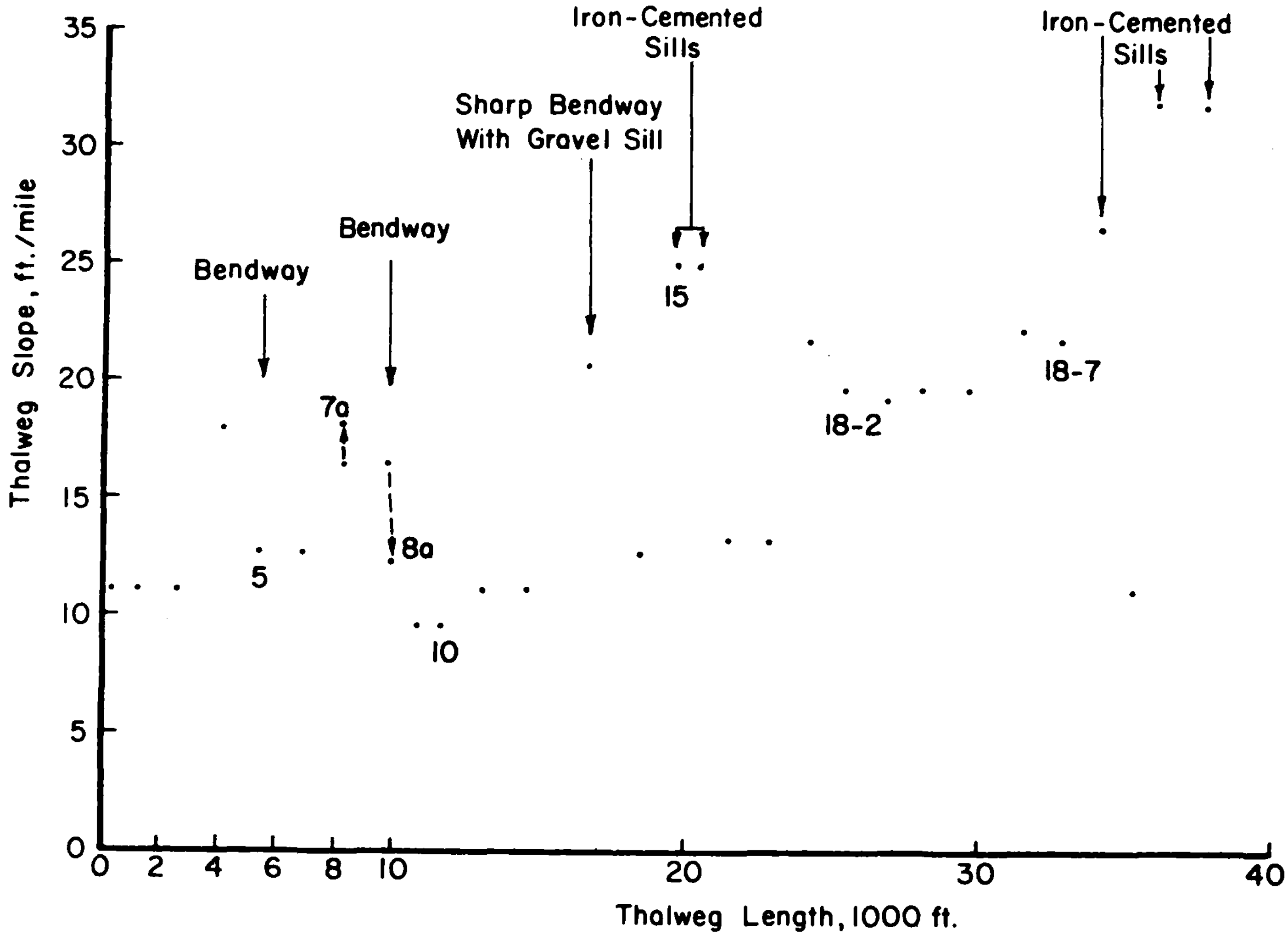

Figure 30 Thalweg profile for Goodwin Creek, from 1977 survey.

channel, we conclude that channel morphology is an independent variable influencing flow properties (the dependent variable). The stratigraphic controls, the variation in channel width and depth, the cemented sills and the unusually large bendways all will probably influence flow characteristics including the distribution and magnitude of boundary shear stresses, secondary flows and total flow resistance. For longer time periods, these variables will have a reversed role suggesting that long-term stability studies should be based on rate process theory (Kelly et al., 1978) rather than on concepts based upon critical conditions. A corollary of this reasoning is that the present drainage system of Goodwin Creek is not stable; it is immature and will change through time.

6.5 CONCLUSIONS

Goodwin Creek channel is not a true alluvial channel within the time constraints of this study. An additional group should be added to this classification, possibly termed stratigraphic-controlled channels, to more accurately reflect variable dependence or independence with time. The stratigraphic controls, the variation in channel width and depth at point locations, the cemented sills and the unusually large bendways are probably independent variables affecting flow properties (the dependent variable) for this study of channel stability. The dependent hydraulic properties include the distribution and magnitude of boundary shear stress, secondary flows and total flow resistance. For longer time periods, these variables will have a reversed role.

One additional observation, not previously discussed, concerns thalweg length. Many straight channels have low-flow paths which meander within the existing channel. Thalweg lengths for such channels are pertinent to low-flow conditions only. Higher flows will follow a less tortuous path which inherently has a higher slope. For these channels, thalweg slopes may not be representative of slopes for flows of interest.

7 SUMMARY

7.1 RESULTS

1. The present conditions of channel stability or instability for Johnson and Goodwin Creeks have evolved from site specific conditions, stratigraphic controls and system chracteristics. Bank instability for Johnson Creek is prevalent downstream of a major knickpoint whereas the banks upstream of the knickpoint are relatively stable. The knickpoint has progressed upstream at an average rate of about 525 feet per year for the last 35 years, eroded through the cohesive polygonal-structured paleosol II bed materials and sufficiently lowered bed elevations downstream of the knickpoint to accentuate gravity-induced failure of the banks. Reaches downstream of the knickpoint have sand to gravel beds with transport processes dominating stability relations. This type of instability has been termed dynamic reach instability (the unstable reach moves through the system with time). Goodwin Creek, on the other hand, has undergone appreciably less thalweg lowering due to the presence of iron-cemented sandstone outcrops in the channel bed which function as temporary bed-control sills and due to the large amount of gravel bed material. Excessive lateral movement of the Goodwin Creek channel has occurred at unusually large bendways and this type of instability has been termed static reach instability (the unstable reach remains at the same position within the system).
2. Gravity-induced failure is the most frequent form of bank instability. Failure of paleosol I and postsettlement materials is accentuated by the presence of vertical tension cracks which develop parallel with the bank. This tension crack development results from the relatively unweathered and hence isotropic nature of these materials. Paleosol II materials have a well developed polygonal structure which controls stability. The seam materials between the polygonal blocks are excessively weak, resulting in weakness planes separating individual blocks. Block loading by water leads to block failure. The failure rate is accentuated by the presence of easily eroded toe materials, either channel lag or bog-type deposits.

3. Bank instability is essentially a three stage process: (a) gravity-induced failure delivers slough to a bank toe position, (b) the slough is continuously disaggregated by weathering forces and (c) discrete particles are removed by fluid forces. In the study channels, this removal is rapid with little slough remaining in the failure location from one year to the next.
4. Bed failure by headcut movement is extremely complex. Headcuts typically occur in paleosol II materials with a well developed polygonal structure. Failure is initiated by a chute forming through the cohesive materials concurrent with removal of weak seam materials. Individual blocks, thus isolated, roll to the chute and are moved downstream by high velocity flows. The initial chute formation and seam material removal are probably dependent upon low flow conditions.
5. Goodwin Creek channel is not a true alluvial channel within the time constraints of this study. An additional group should be added to river classification, possibly termed stratigraphic-controlled channels, to more accurately reflect variable dependence or independence with time. The stratigraphic controls, the variation in channel width and depth at point locations, the cemented sills and the unusually large bendways are probably independent variables affecting flow properties, the dependent variables, for this study of channel stability. The dependent hydraulic properties include the distribution and magnitude of boundary shear stress, secondary flows and total flow resistance. For longer time periods, these variables will have a reversed role.
6. The preceding results illustrate the complexity of channel failure processes and the difficulties involved in simulating such conditions in process-based models. Failure occurs in reaches of excessive energy expenditure typically associated with nonuniform flow, necessitating 3-dimensional simulation models for accurate representation of field conditions.
7. The distributions and properties of the valley-fill units (the units imposing stratigraphic controls) and their ^{14}C ages indicate that the dominant process controls of formation for these units was paleoclimate and base level fluctuations. This finding enhances the predictive capabilities for extrapolating

results from the study watershed to other locations subjected to similar late-Quaternary paleoclimatic and base level conditions. Similarly, these results illustrate the utility of the valley-fill stratigraphic record as a measure of paleoclimatic conditions.

8. The geologic studies have established that the presently-mapped stratigraphy is not accurate in the study area and probably in a large part of North Mississippi. The surface of the Zilpha is disconformable, representing an erosion surface which we feel has regional significance. Groundwater is perched above this surface due to the relative impermeability of the Zilpha material. Additionally, the erosion surface is not congruent with surface watershed definition, creating the possibility of groundwater transfer between watersheds. This greatly complexes water budget considerations inherent in the detailed Goodwin Creek study. Resistivity methods appear to have great utility for further defining the relief on the Zilpha surface.
9. The uncertainty concerning the nature and distribution of the near-surface geologic units limits full development of capabilities for predicting properties of the valley-fill units. The geologic materials are source materials for the valley-fill deposits and both the source availability and controlling processes must be accurately defined for full development of predictive landscape models.

7.2 RECOMMENDATIONS

1. Relations between valley-fill units, failure mechanisms and failure rates should be quantified. (We will initiate this activity as soon as gaging station installation is completed.)
2. The landscape is a complex arrangement of landforms and landform elements in a physical sense but is systematic and logical when defined on the basis of controlling process or processes. A complete understanding of the landscape, based on controlling process or processes, is essential in order to more efficiently manage the present pervasive environmental problems such as those associated with channel instability.

Hopefully, such an understanding would lead to the development of landscape models of sufficient detail to facilitate coupling with application models. We believe that this coupling of models would:

a. simplify application model requirements,

b. maximize predictive capabilities with respect to time and space,

c. result in better definition of the basic processes underlying specific environmental problems.

3. In order to better understand the landscape, a prerequisite to landscape model development, the following landforms and landform properties should be better defined:

   a. Loess - the ages of the loess, the nature of the contacts between individual loess units and the nature of the loess to valley fill contact.

   b. Valley terraces - the distribution and ages.

   c. Valley-fill deposits - comparable studies east of the present study area to verify the valley-fill sequence and establish the maximum depth of Quaternary valley erosion, and west of the present study to additionally verify the valley-fill sequence and establish relations of these deposits with those in the Mississippi River valley.

   Additionally, geologic studies should be conducted to better define material overlying the Zilpha surface. Secular variation or other paleomagnetic determinations may be a useful tool for dating layered clay bodies in this material. The possibility of a (buried) ancestral Mississippi River channel between the present study area and the bluff line should be evaluated.

4. Relations between soil map units and valley-fill deposits should be evaluated. To the degree that these are related, the soil map units could be used to infer the general nature of the subsurface deposits.

5. The dependence of flow properties on stratigraphic and channel morphometric controls should be evaluated. Secondary flow production is extremely important as such flow influences the distribution and magnitude of bed shear stresses and the flow

resistance. Full definition of the influences of stratigraphic and morphometric controls may facilitate classification of such controls into functional units which would have direct utility in channel stability evaluations.

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The authors thank all the landowners for their cooperation and help during the field investigations. T. A. Woodruff was particularly helpful; he stored considerable amounts of equipment for us during the drilling program. The competence of the Corps of Engineers drilling crews contributed materially to the success of the subsurface investigations. The assistance of various staff members and graduate students of the Geology Department, University of Mississippi, is also acknowledged.

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Addendum 1

Low-weight carbon samples, not analyzed.

Stream, County	Drill Hole	Depth (m)	Sed. Lab. No.
Arkabutla, Panola	AR-1, Fig. 11	13.3-13.7	C-134
Brushy, Calhoun	BR-1, Fig. 11	6.1	C-128
Brushy, Calhoun	BR-1, Fig. 11	8.8-9.1	C-129
Cane, Union	CN-1, Fig. 11	7.6-9.1	C-150
Chiwapa, Lee	CH-2, Fig. 11	4.0-4.9	C-172
Chiwapa, Lee	CH-3, Fig. 11	5.2-6.1	C-171
Coldwater tributary, DeSoto	EG3-7(a)	15.2	C-193
Coldwater tributary, DeSoto	EG3-10(a)	27.4	C-204
Cypress, Yalobusha	CY-1, Fig. 11	3.0-4.4	C-173
Cypress, Yalobusha	CY-1, Fig. 11	4.6-6.1	C-174
Cypress, Yalobusha	CY-1, Fig. 11	6.1-7.0	C-175
Cypress, Yalobusha	CY-1, Fig. 11	7.0-7.6	C-176
Hell, Union	HE-1, Fig. 11	4.6-4.7	C-152
Long, Grenada	LG-1, Fig. 11	8.4	C-120
Lappatubby, Pontotoc	LA-1, Fig. 11	5.8-6.1	C-170
Mill, Union	ML-1, Fig. 11	5.5-6.1	C-154
Mill, Union	ML-1, Fig. 11	4.6-5.5	C-156
Mill, Union	ML-1, Fig. 11	4.0-4.3	C-157
Mill, Union	ML-1, Fig. 11	7.9-9.1	C-159
Mill, Union	ML-1, Fig. 11	5.5	C-163
Mill, Union	ML-1, Fig. 11	6.4	C-164
North Tippah, Tippah	NT-1, Fig. 11	3.6-4.6	C-143
Oaklimeter, Marshall	OA-2, Fig. 11	5.6	C-135
Oaklimeter, Benton	OA-1, Fig. 11	6.1-6.4	C-140
Perry, Grenada	PY-1, Fig. 11	7.2-7.3	C-106
Pigeon Roost, DeSoto	PR-1, Fig. 11	2.7-3.0	C-177
Tallahatchie, Union	T-13, Fig. 11	5.2-5.5	C-144
Tallahatchie, Union	T-13, Fig. 11	5.8-6.1	C-146
Tallahatchie, Union	T-14, Fig. 11	6.1-6.4	C-147
Tallahatchie, Union	T-14, Fig. 11	7.6-8.5	C-149
Tallahatchie, Union	T-15, Fig. 11	5.5-6.1	C-155
Tallahatchie, Union	T-20, Fig. 11	6.1-7.6	C-160
Tallahatchie, Union	T-20, Fig. 11	5.3-6.1	C-161
Tallahatchie, Union	T-20, Fig. 11	7.6-8.5	C-162
Tallahatchie, Union	T-15, Fig. 11	6.1-7.3	C-165
Tallahatchie, Union	T-15, Fig. 11	7.3-7.6	C-166
Tallahatchie, Union	T-15, Fig. 11	4.6-5.5	C-167
Tillatoba, Tallahatchie	TL-1, Fig. 11	10.7	C-117
Tillatoba, Tallahatchie	TL-1, Fig. 11	14.8-15.2	C-118
Tippah, Marshall	TI-3, Fig. 11	4.3-4.6	C-136
Tippah, Benton	TI-1, Fig. 11	6.1-7.6	C-141
Tippah, Benton	TI-1, Fig. 11	7.8-9.1	C-142

(a) Samples supplied by Mississippi Geological Survey.